Monitoring of whole body cryotherapy effects by thermal imaging: preliminary report

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Abstract

In whole body cryotherapy the whole human body is exposed to low temperature below -100°C in a special room called cryogenic chamber for a very short period of time (2-3 minutes). The impact of cold can cause many different biochemical and physiological reactions of the organism.

The skin temperature response due to whole body cryotherapy was studied by means of infrared measurements. The thermograms of chosen body parts of patients suffering from low back pain were performed before and after whole body cooling on the 1st, 5th and the last (10th) day of medical treatment. Infrared imaging performed after cold impact owing to the enhancement of the skin temperature profile may reveal a slight decrease of the inflammatory states as a result of the 10 sessions of cryotherapy.

KEYWORDS: infrared measurements, whole body cryotherapy, thermovision diagnostic.

1. Introduction

Modern cryotherapy involves local and whole body cryotherapy. At the beginning only local cold therapy was used in medicine [1-4]. Nowadays the whole body therapy, where patient is subjected to temperature below –100°C (usually ~ -120°C) in the special room called the cryogenic chamber, has developed quickly [5-7]. It takes only 2-3 minutes but it can cause the important effects in human organism.

The first cryogenic chamber was made in Japan in 1978 where Yamauchi used short stay in the cryogenic chamber in treatment of patients' sufferring from joints diseases. In Europe R. Fricke (Germany) used whole body cryotherapy to treat ill joints and worked out the first standards of using the whole body cryotherapy as a part of medical treatment. First cryogenic chamber in Poland was built in 1989 as the second one in Europe and the third in the world. Over the last few decades many cryogenic chambers have been built in the number of countries all over the world [7].

The whole body cryotherapy is applied in different diseases: inflammatory states of spinal vertebrae joints, degeneration and inflammatory states of joints (*monoarthritis* and *oligoarthritis*) and *periarthritis* [8], rheumatism, low back pain diseases [9] and *sclerosis multiplex* [10]. The positive influence of whole body cryotherapy on mental health and *osteoporosis* preventive treatment was also reported [7, 10, 11]. Wide application of cryotherapy is found in sport medicine [12] and biological recovery. The cold treatment causes reduction of pain in the post-operative period after reconstructive surgery of the joints and shortening of the recovery time of the rehabilitation.

The infrared studies of the temperature response due to whole body cryotherapy showed that the application of cold on whole human body causes an essential drop of skin temperature whereas the internal temperature does not exceed the thermoregulation range during cryotherapy session [9, 13,]. Thermal mapping is diversed by local blood flow, degenerative and inflammatory state of tissues. It was reported [9, 14] that an enhancement of the skin temperature profile could therefore increase the diagnostic sensitivity of infrared imaging in patients. The increase of heat losses as well as metabolic processes are also discussed [14].

The broadening of the temperature range observed on the thermal imaging after whole body cryotherapy made it possible to monitor the health state of patients exposed to cold during treatment.

2. Materials and Methods

The experimental group consisted of 30 patients (23 male and 7 female) aged 41,5 ± 12,0 suffering from the *low back pain* and 16 healthy people (10 male and 6 female) aged 25,6 ± 3,9. From this experimental group six patients suffered from *spondyloarthrosis* (1 female and 5 male) aged 35,8 ± 13,9 treated only by whole body cryotherapy and kinetic therapy i.e. physical exercises were chosen to monitor the influence of cold treatment on their health state.

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The thermal imaging of regions of interest was performed at the beginning (first session), in the middle (fifth session) and at the end of the rehabilitation cycle (tenth session), before as well as immediately after whole body cryotherapy, respectively.

The distribution of the skin surface temperature was monitored by using of a Thermovision Camera AGEMA Type 470 made in Germany with the possibility of computing imaging on the basis of software Irvin 5.3.1. Before each measurement session the thermovision camera was calibrated by black body (thermal sensitivity of thermovision camera was <0,1°C at 30,0 °C). The calibration indicated the temperature measurement error which was ±0,3 °C in the investigated temperature range.

Stability of cooling temperature inside the cryogenic chamber during cryotherapy was -91,2 ± 1,3° C and -94,3 ± 1,3° C at the height of 100 and 145 cm, respectively. This, however, could have little influence on single measurement as reported in [11].

Statistical analysis were done with Statistica 5.1 using Students' t-tests and ANOVA/MANOVA. Differences with a p<0,05 were regarded as significant.

Thermal images were recorded in a special measurement room outside the chamber fulfilling established standards. Stability of temperature in the measurement room was 21,5 ± 1°C. In order to catch the dynamic response of the skin temperature due to cold impact, thermal imaging of the patients was performed immediately after cryotherapy.

The investigations were carried out at the Provincial Centre of Rheumatologist in Goczałkowice Zdrój (WORR) where liquid air was used to get very low temperatures (-120°C) in the cryogenic chamber. The studies were performed during the normal programme of rehabilitation in the Centre.

All patients were examined by the physician. They were requested not to smoke, drink alcohol or hot drinks for 4 hours before experiment.

Ethical approval was obtained by the Ethical Committee of the Silesian Medical University (No. NN-013-144/I/02).

3. Results

The thermal imaging and appropriate temperature analysis for chosen patients suffering from *spondyloarthrosis* performed at the beginning (A), in the middle (B) and at the end (C) of the rehabilitation course are presented in Figures 1-4.

Comparing the thermograms performed before (**a**) and immediately after (**b**) whole body cooling, one can see that body skin surface temperature is more diverse after whole body cryotherapy than before one. Therefore it is possible to use thermal imaging in diagnosis. There are some temperature anomalies in the vicinity of loins which are much better visible on the thermograms performed after (**b**) whole body cryotherapy than before one (**a**). It should be noted that the first stay of the patients in the cryogenic chamber is only 2 minutes while the

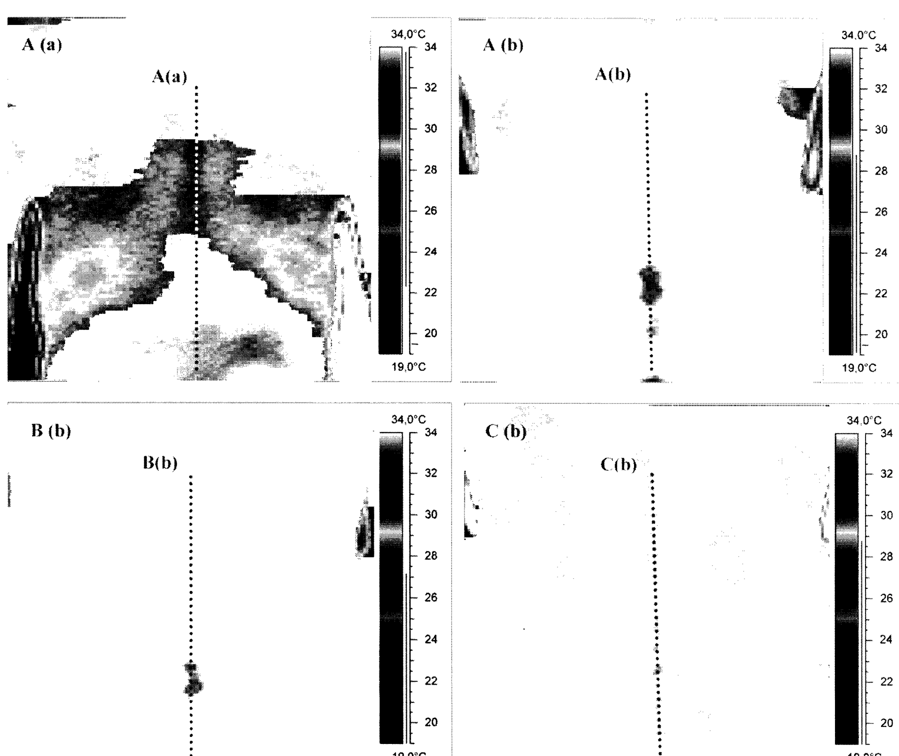

Fig. 1. Thermograms of the lower back with marked vertical lines along the spine in the range Th5/Th6 – L5/S1 for patient KS suffering from *spondyloarthrosis*, performed at the beginning (A), in the middle (B) and at the end of the (C) treatment course, before (**a**) and immediately after whole body cryotherapy (**b**), respectively.

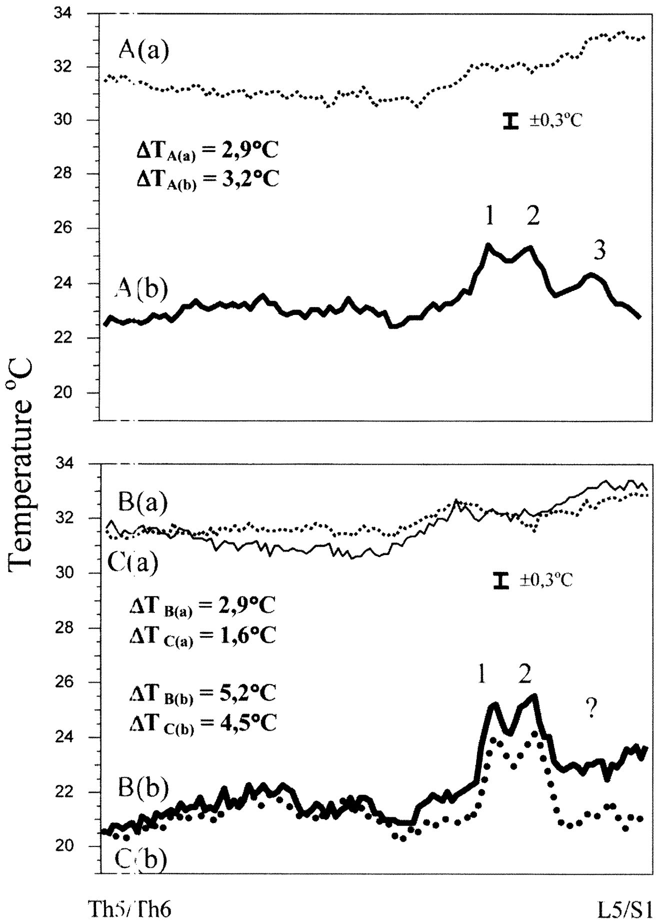

FIG. 2. The temperature plots along the spine (patient KS) in the range Th5/Th6 – L5/S1 performed before (**a**) and after (**b**) whole body cryotherapy for man sufferring from *spondyloarthrosis* on the first (A), fifth (B) and tenth session of whole body cryotherapy (C), respectively.

next sessions last 3 minutes causing deeper cooling of the body.

Thermograms A-C (**b**) in Figure 1 reveal that the main inflammatory state is located in the vicinity of the vertebrae L1-L3 and the smaller one in the vicinity of the vertebrae L4. The areas of higher temperature in the range L1-L3 correlated with inflammatory state are visible during whole treatment course (even after 10th session of body cooling) while the area of higher temperature connected with vertebrae L4 seems to be a little reduced in the middle of rehabilitation course (5th session, Figure 1 B(b)).

To see the problem more clearly, the plots of the temperature along vertical line (marked in Figure 1) performed at the first (A), fifth (B) and tenth day of rehabilitation (C) before (**a**) and after (**b**) whole body cryotherapy are presented in Figure 2. The temperature dependences obtained directly after cryotherapy session (curves **b**) unlike curves **a** indicate the marked increase of the temperature in the lower lumbar region of the spinal vertebrae due to the inflammatory states visible in the thermograms (Figure 1). The body cooling conditions on the fifth (B) and tenth (C) day are nearly the same so it is possible to compare the curves. Detail analysis of curves A-

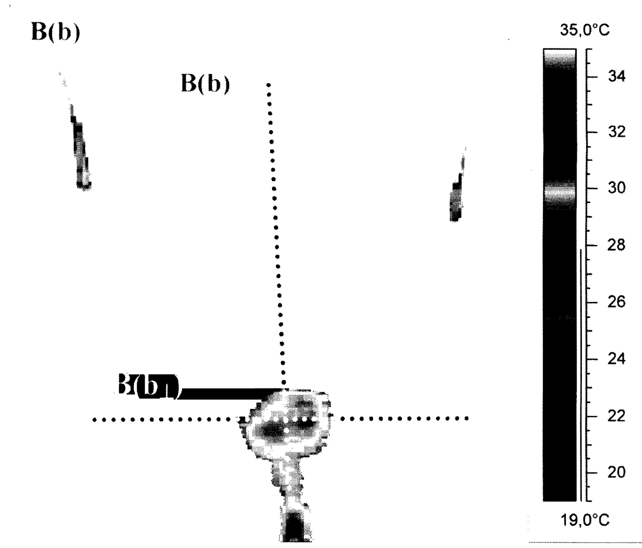

FIG. 3. The thermograms of the back of patient MK performed in the middle (B) of the rehabilitation cycle obtained after whole body cryotherapy (**b**).

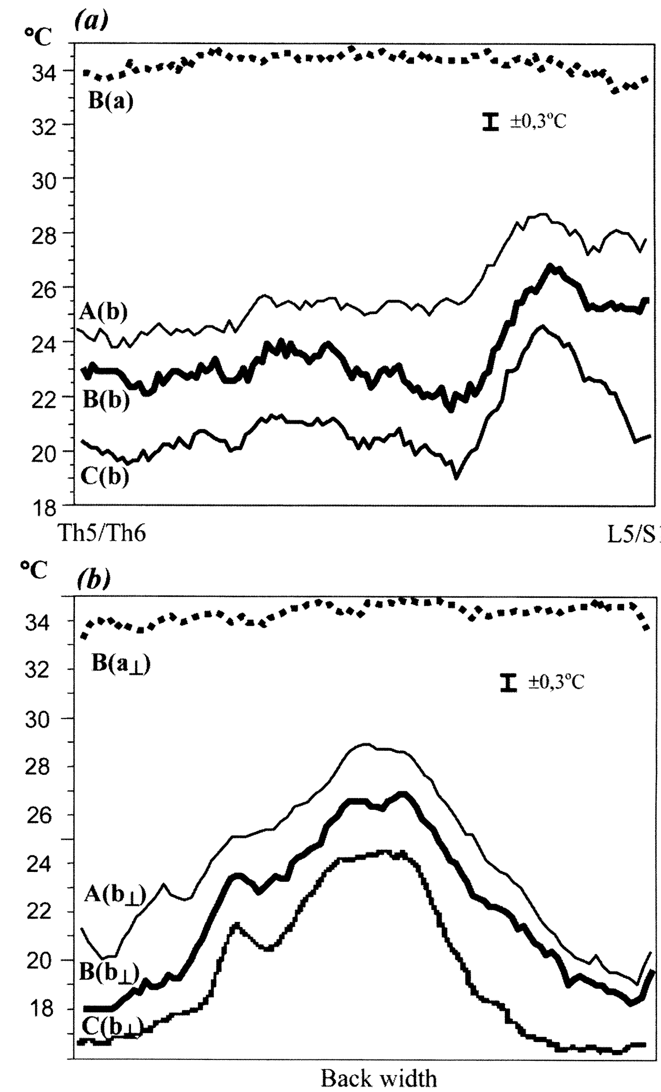

Fig. 4. The plots of the temperature along vertical line characterizing spinal vertebrae in the range Th5/Th6 to L5/S1 (*a*) and plots along horizontal line (*b*) perpendicular to spinal vertebrae in the range L2/L3 performed for patient MK suffering from *spondyloarthrosis* (Figure 3).

C(**b**) show that temperature peaks 1 and 2 correlated with inflammatory states of L1-L2 and L2-L3 vertebrae are visible during whole cold treatment time. However the weak peak 3 in the region L4 seen at the beginning of treatment seems to disappear in the middle of whole body cryotherapy (B(**b**)).

The thermogram of the other patient (MK) suffering from *spondyloarthrosis* obtained after whole body cryotherapy (B(**b**) in Figure 3) revealed one wide area of inflammatory state in lower lumbar region that was not seen on thermograms performed before cold impact. For better description of this inflammatory state and to underline the differences between shape and area under peaks the plots of the temperature along vertical line in the range Th5/Th6 to L5/S1 (curves A(**b**) - C(**b**)) and horizontal line perpendicular to the spinal vertebrae in the range L2/L3 crossing the diseases change area (curves A($\mathbf{b}_\perp$) - C($\mathbf{b}_\perp$)) are illustrated in Figure 4a and 4b, respectively. The curves after the 5^{th} and 10^{th} session of whole body cooling lasted 3 minutes each. It is noteworthy that the horizontal curves $\mathbf{b}_\perp$ show the temperature changes due to inflammatory states of the adjoining tissues which accompany the vertebrates' diseases. One can see some differences in the temperature plots following the number of cryotherapy session. It seems that the area of higher temperature characterizing the inflammatory state becomes a little smaller with the number session of whole body cryotherapy.

Similar slight effects of the whole body cryotherapy in lumbar inflammatory states were also observed for the other studied patients.

In addition statistical analysis was also performed. The maximum (T_{max}) temperature parameter, before and after cryotherapy, derivated from the chosen lines was taken into account. Some statistical results obtained for line characterizing the spinal vertebrae in the range Th5/Th6 – L5/S1 are presented in Table I and II.

T-tests confirmed the significant differences between T_{max} obtained before and after whole body cryotherapy ($p<<0.05$). The MANOVA tests showed that there are significant differences ($p<0,05$) between temperature parameters connected with the cryotherapy treatment. The null hypothesis for T_{max} after whole body cryotherapy could be rejected with $p=0,013$ (Table I). In these case the NIR test (Table II) indicated the statistical significant differences between T_{max} at the beginning (A(b)) and the end (C(b)) as well as in the middle (B(b)) and the end (C(b)) of the whole body cryotherapy treatment. The most interesting is the second result ($p=0,036$) due to the same conditions of body cooling (3 minutes) on the fifth and tenth day. Obtained statistics are consistent with thermograms and temperature plots showing a small decrease of the intensity of inflammatory state. However, an increase of the number of studied patients would be necessary to make the results more objective.

4. Discussion

It is known that the inner human organism temperature due to homeothermy oscillates in the thermoregulation range of about 0,5-0,7 °C daily. Skin and superficial layers under the skin can change their temperature in the wider range due to environment temperature. When the body temperature drops rapidly (whole body cryotherapy), adaptation mechanisms have to be developed to avoid such stress. Physiological mechanisms such as surface vessels contraction, muscle trembling and shivers protect organism against excessive cooling. These mechanisms are controlled by hypothalamus. The thermoregulation system is also assisted by thermal receptors of peripheral (skin) and internal organs. When the environment temperature is too low the metabolism in the body layer slows down and increases in the testicle [7, 14]. The inner body organs such as heart,

Table I. The effects (number of cryotherapy sessions and cold impact) influence on maximal temperature (T_{max}) derivated from chosen lines characterizing the spinal vertebrae in the range Th5/Th6 – L5/S1.

MANOVA Effect	df Effect	MS Effect	df Error	MS Error	F	p
Influence of number of cryotherapy sessions on T_{max}	2	6,788	15	1,141	5,950	**,013**
Influence of cold impact on T_{max}	1	451,562	15	1,006	448,944	,000

Table II. Results of NIR test for T_{max} obtained from the thermograms performed on the first (A), fifth (B) and tenth session of whole body cryotherapy (C), before (a) and after (b) whole body cryotherapy, respectively.

	A(a)	A(b)	B(a)	B(b)	C(a)	C(b)
	34,033	27,966	34,083	26,866	33,500	25,533
A(a)		,000	,932	,000	,371	,000
A(b)	,000		,000	,077	,000	**,001**
B(a)	,932	,000		,000	,329	,000
B(b)	,000	,077	,000		,000	**,036**
C(a)	,371	,000	,329	,000		,000
C(b)	,000	**,001**	,000	**,036**	,000	

liver, brain and kidneys should keep up nearly constant temperature. Disease process leads to increase of temperature in case of inflammatory states while the lower temperature is associated with the degeneration states. The skin temperature reflects the dynamic balance of heat loss from the body and heat deposited in metabolically active tissues. In addition the skin can manifest the diseases processes becoming under its surface [9, 13, 14]. The change of temperature influences the power of infrared radiation emitted from the skin and can be easily detected using the infrared technique which is sufficient for study of human body range temperature [1, 15, 16, 17].

Impact of very low temperature (-120°C) used in the whole body cryotherapy causes the skin temperature following the low environment temperature. The body loses its heat due to the difference between internal and external temperature (inside the cryogenic chamber) by conduction, convection and radiation. Radiation is usually thought to be the dominant mechanism of the heat loss (60%). It was estimated [14] that the net emission of heat energy by body radiation according to Stefan-Boltzmann law was nearly five times higher and conduction heat increased about two times in the whole body cryotherapy conditions. It was also found according to empiric formula called Kleiber's law that the increase of metabolic rate would have to be 7 times higher in cryogenic conditions [14].

It follows from our studies that the cold impact causes essential changes in thermal behaviour of the tissues as well as local blood flow in the superficial skin layer and as a result the healthy and sick tissues become more diverse (see also [9, 14]). Increase of resolution and sensitivity of thermal mapping after cryotherapy can be useful in diagnosis of patients subjected to cold treatment. It is noteworthy that thermograms (**b**) facilitate an accurate localisation of inflammatory and degenerative states.

Whole body cryotherapy usually involves 10 sessions of body cooling therefore it is possible to monitor the effects of treatment in time. Analysis of thermal mapping should be performed carefully because the skin temperature response depends on the magnitude of minus temperature and cooling time in the cryogenic chamber.

Monitoring the whole body cryotherapy effects by thermal imaging of the studied patients indicates a little trend to decrease the inflammatory state located in the adjoining to spinal vertebrae tissues due to cold treatment while the main inflammatory state is remained.

Additionally, performed analysis of the polls of 46 patients showed that the whole body cryotherapy was well tolerated by patients who reported the reduction of the level of pain and improvement of patients' health condition. From the patients' point of view the whole body cryotherapy was beneficial. After a 10 day cycle of cryotherapy a slight decrease of pain level was reported by 39,3% of the patients and 53,6% patients noted a marked decrease while 7,1% of patients did not feel any improvement at all. Similar positive effects of the cryoptherapy were reported earlier [5, 11]. It should also be noted that pain may return in several months and the patients had to repeat the whole therapy course [11].

It is important to deepen the studies and improve the statistic evaluation because of application of whole body cryotherapy as assisting method in treatment in many medical branches.

5. Conclusions

An enhancement of the skin temperature profile due to whole body cooling could be used in diagnosis and monitoring during the medical treatment involving whole body cryotherapy.

Infrared imaging performed after whole cryotherapy of patients suffering from low back pain reveals a slight decrease of the inflammatory states during 10 sessions of whole body cryotherapy.

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