J Therm Anal Calorim (2010) 102:113–119
DOI 10.1007/s10973-010-0873-y

Thermovision diagnostics in chosen spine diseases treated by whole body cryotherapy

Armand Cholewka · Zofia Drzazga · Aleksander Sieroń · Agata Stanek

Received: 24 January 2010 / Accepted: 5 May 2010 / Published online: 21 May 2010

Abstract The non-invasive infrared technique was used in case of the thermal imaging of patients suffering from spine diseases. Measurements were performed for the group of 50 patients during whole body cryotherapy at the second, fifth and tenth day of the rehabilitation cycle. An enhancement of the profile of skin temperature due to body cooling caused an increase in the diagnostic sensitivity of thermovision. The temperature parameters such as temperature contrast ($\Delta T = T_{max} - T_{min}$) and relative change of contrast ratio defined as $(\Delta T)/(T_{mean})$ in the region of interest (ROI's) were used to point out differences between the healthy patients and patients suffering from ankylosing spondylitis, sciatica and spondyloarthrosis. The value of the thermovision diagnostic in the case of spine diseases was confirmed by statistical analysis.

Keywords Thermal imaging · Temperature · Cryotherapy

Introduction

Whole body cryotherapy is a medical modality that is usually correlated with typical rehabilitation procedures [1, 2]. In this kind of treatment patient is influenced by very low temperature (lower than −100 °C) applied to the whole body surface for a period of 2–3 min in the cryogenic chamber in order to cause physiological and biochemical reactions in the organism. This therapy facilitates doing exercises and finally leads to the shortening of the process of healing [1, 2]. There have been a lot of papers about cold treatment [1, 2] which include whole body cryotherapy but only few of them touched the problem of thermal imaging due to cold impact on human body [3–5]. Nowadays the whole body cryotherapy is being used widely in many applications, especially in motion organ diseases such as degeneration and inflammatory states of joints (*monoarthritis* and *oligoarthritis*) and *periarthritis*, rheumatism, low back pain diseases, inflammatory, degeneration states of spinal vertebrae joints and fibromialgia [2, 6–13]. It was also reported that cryotherapy has a positive influence on mental health which can be explained by an increase of concentration of some hormones. What is more, it helps to destroy the free radicals and is being used in *osteoporosis* preventive treatment [7]. Moreover the cryotherapy has applications in sclerosis multiplex and other nervous system diseases. Diseases like *sciatica*, *discopathy* and many other spine lesions are connected with perturbations of nervous system [14–17].

Commonly occurring spine diseases are *ankylosing spondylitis* (AS), *sciatica* and *spondyloarthrosis* (SP). AS previously known as Bechterew's disease is a form of *spondyloarthritis* and has genetic predisposition. It is a chronic, painful, inflammatory arthritis, primarily affecting spine and sacroiliac joints. It can even cause a fusion of the spine and the inflammatory state occurs in almost all joints of the spine. It is also called the bamboo spine [18, 19]. AS is mainly male disease. Sciatica is a set of symptoms including pain that may be caused by compression and irritation of one of five nerve roots that give rise to the sciatic nerve or by compression or irritation of the sciatic

A. Cholewka (✉) · Z. Drzazga
A. Chełkowski Institute of Physics, Department of Medical Physics, University of Silesia, Uniwersytecka 4, 40-007 Katowice, Poland
e-mail: armand.cholewka@gmail.com

A. Sieroń · A. Stanek
Department and Clinic of Internal Diseases, Angiology and Physical Medicine, Medical University of Silesia, Batorego 15, 41-902 Bytom, Poland

nerve itself. The pain is usually felt in the lower lumbar region, one leg or even in the foot. Sciatica is generally caused by the compression of lumbar nerves L4 or L5 or sacral nerves S1, S2 or S3 and far less commonly by compression of the sciatic nerve itself. Inflammatory states of soft tissue in the vicinity of loins are also commonly occurring symptoms. The *SP* is also a spine disease which occurs mainly in the lumbar region of spine and in the cervical. This progressive destruction of the facet joints and is characterized by loss of articular cartilage and production of osteophytes. This disease can lead to a narrowing of the neural foramina in the lumbar regions and stenosis of spinal canal causing inflammatory state and back pain [18, 19].

One type of therapy which is used to treat *AS*, *SP* as well as *sciatica* is whole body cryotherapy. Therefore, this work presents systematic studies of patients with spine diseases due to body cooling by means of thermal imaging.

Materials and methods

The total study population consisted of 18 patients suffering from *AS* (18 male aged 50.6 ± 8.0), 15 patients suffering from *sciatica* (13 male, two female aged 44.7 ± 7.6), six patients suffering from *SP* (six male aged 46.0 ± 11.7) and 11 healthy people (11 male aged 34.0 ± 7.9). The line marked along the spine in the range of vertebrates from Th1/Th2 to L5/S1 was taken into consideration for whole study population.

The investigations were carried out at the Provincial Centre of Rheumatologist in Goczałkowice Zdrój (WORR), where the cryogenic chamber was installed. In order to get very low temperatures (−120 °C) in the cryogenic chamber, liquid air was used. All patients were influenced by very low temperature in the cryogenic chamber for 3 min.

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

The distribution of the skin surface temperature was monitored by means of a Thermovision Camera A40M calibrated by a black body. The camera sensitivity was 0.07 K. High-resolution images (320 × 240 pixels) can be obtained with more than 76,800 individual measurement points per image at a refresh rate of 50/60 Hz.

The thermograms of chosen regions of interests (ROI) were performed before and immediately after the whole body cryotherapy, at the second (beginning), fifth (middle) and tenth (last) day of treatment in a special room outside the cryogenic chamber where the temperature was stabilized (22 ± 1 °C). The distance between the camera and the body was about 1.2–1.5 m (depending on height and size of the patient). It was necessary to follow the standard protocol of infrared imaging in medicine [20, 21].

Statistical analysis were done with Statistica 7.1. Differences with a $p < 0.05$ were regarded as significant.

Results and discussion

Representative thermograms of the back of a healthy man (H) and a patient suffering from AS performed before (B) and after (A) whole body cryotherapy session at the same period of rehabilitation cycle (fifth day of cryotherapy treatment) in the same temperature scale are shown in Fig. 1.

One can see from Fig. 1 that a significant decrease of skin temperature is observed after a cold impact. Thermal mapping obtained after cryotherapy is clearer and reveals marked temperature differentiation that increases a potential diagnostic value of thermal imaging which was mentioned in previous papers [3–5]. It follows from comparison of

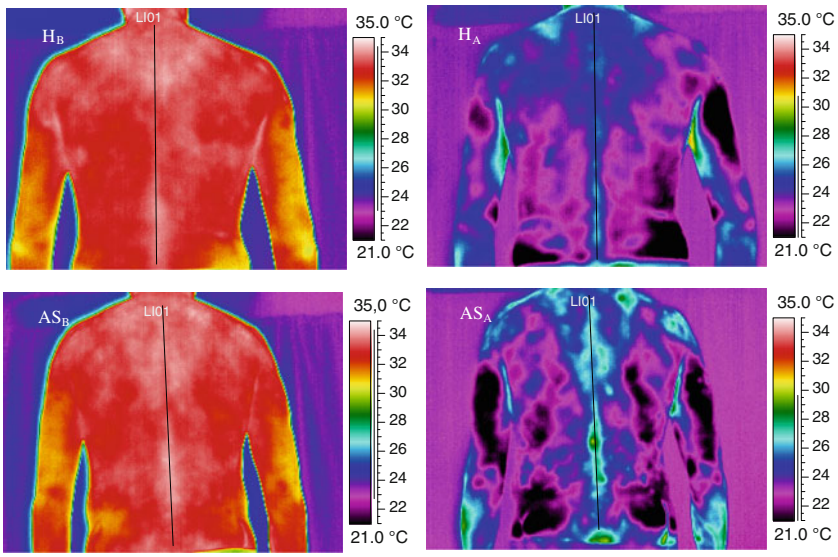

Fig. 1 Thermograms of patients' backs with marked lines along the spine of a healthy man (H) and a patient suffering from *ankylosing spondylitis* (AS) performed before and after whole body cryotherapy at the same period of the rehabilitation cycle

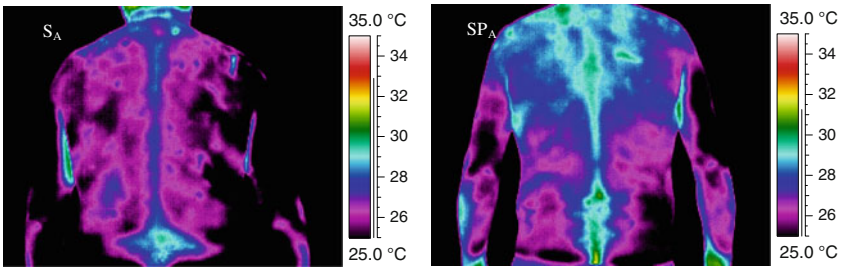

Fig. 2 Thermograms of the backs of patients suffering from *sciatica* (S) and *spondyloarthrosis* (SP) performed after whole body cryotherapy at the same period of rehabilitation cycle

temperature variation along the spine that there are no temperature anomalies along the spinal column for the healthy (both before and after cold impact) unlike patients with spine diseases. The areas with increased temperature connected with inflammatory states and with an abnormal decrease of temperature suggesting degeneration states may occur in different spine regions [3–5, 22]. The character of temperature variations depends on the degree of advance and also on the kind of illness. It is interesting to compare that the thermograms of the back of a patient suffering from *AS* (Fig. 1) with representative thermograms of patients with *sciatica* (S) and *SP* performed after cold impact, which are shown in Fig. 2.

For a patient with sciatica, temperature anomalies are observed mainly in the lower lumbar region. The increase in skin temperature occurs not only along the spine, but also in the areas over the tissues adjacent to the spine on its both sides in the lower lumbar region [4]. Similar situations are observed in the thermograms of patients suffering from SP where the inflammatory state is also connected with the lower lumbar region but the range of disease affecting the spine is usually wider than in sciatica (Fig. 2, SP) while tissues adjacent to the spine are less affected.

As far as AS patients are concerned, the areas of higher temperature are observed almost along the whole spinal column (Fig. 1, AS_A) which are a specificity of this disease that is in fact an advanced form of spondyloarthritis. This is a chronic inflammatory arthritis in which the inflammatory state is connected with joints along the whole spine [18, 19]. Therefore, we observed the area characterized by higher temperature almost along the whole spine.

For better insight into the problem the temperature plots along and perpendicular to the spine for studied groups of patients were performed.

Figure 3 shows the plots of the temperature along a vertical line characterizing spinal columns in the range from Th1/Th2 to L5/S1 for patients diagnosed with sciatica (S), SP and AS, respectively, performed before (b) and after (a) whole body cryotherapy. It is clear that plots show marked changes of skin temperature after cold impact in comparison with plots performed in normal conditions, which confirm an increase of thermal imaging diagnostic value. The anomalies of temperature (increase and decrease) can

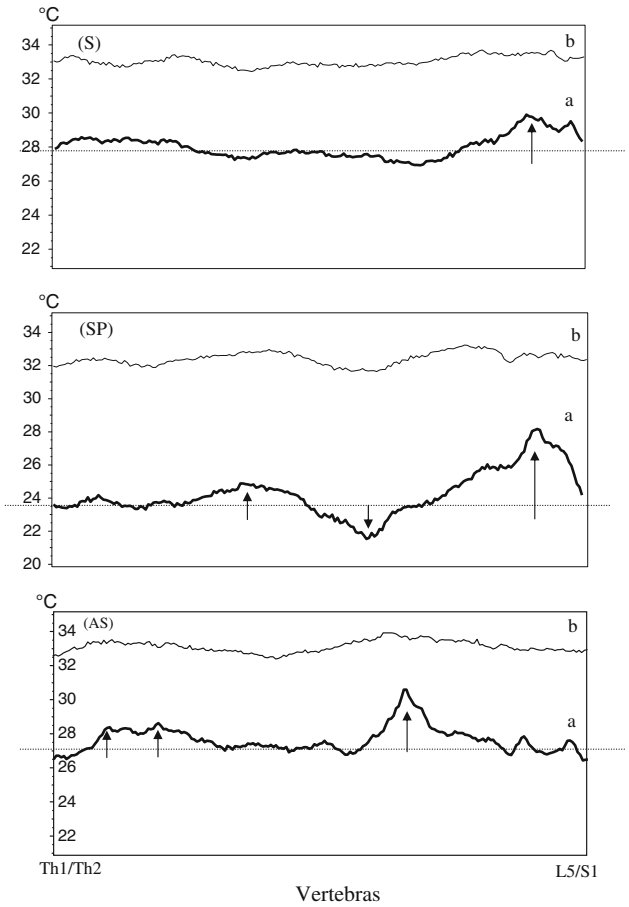

Fig. 3 The plots of temperature characterizing the spinal column in the range of vertebras from Th1/Th2 to L5/S1 for patient with sciatica (S), spondyloarthrosis (SP) and ankylosing spondylitis (AS), respectively, performed before (*b*) and after (*a*) cryotherapy at fifth day of rehabilitation cycle

be treated as connected with different pathology states. One can see that for patient with sciatica (S) increase of temperature is observed only in the lower lumbar region. The temperature plot performed for patient SP point out the marked inflammatory states in the range from L2/L3 to L5/S1, the degeneration state in the vicinity of Th11/Th12 and the weak inflammatory state from Th6/Th7 to Th9/Th10 vertebrates. In the case of patient with AS the skin increased temperature on the level Th5/Th6—Th8/Th9 and Th11/

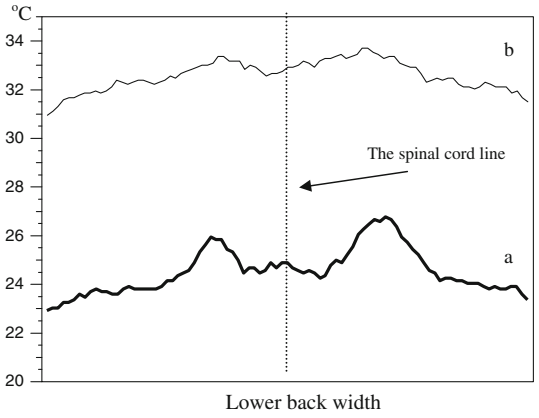

Fig. 4 The plots of temperature along the line perpendicular to the spinal column for patient with sciatica (S), performed before (*b*) and after (*a*) cryotherapy

Th12—L2/L3 indicates inflammatory states occurring almost along all spine. The temperature plots seems to be useful in differentiating between healthy and some spine diseases if the temperature anomalies connected with pathological states are larger than measuring error (the precision was ±2% of the temperature range).

It is noteworthy to test temperature plots along the lines performed perpendicular to the spinal column especially for the patient diagnosed with sciatica in Fig. 4. Marked increase of temperature on both sides of the spine confirm the inflammatory states of tissues adjacent to the spine, which is characteristic for this kind of disease. The temperature anomalies observed along the line perpendicular to the spine were also analysed in detail in our previous work [4]. It was found that increased temperature in adjacent tissues to the spine can occur not only in the case of sciatica,

Table 1 The temperature parameters used in Kruskal–Wallis' test

Temp./ °C	Gender	T_{mean} before cryotherapy	T_{mean} after cryotherapy	T_{max} before cryotherapy	T_{max} after cryotherapy	T_{min} before cryotherapy	T_{min} after cryotherapy	$\Delta T = T_{max} - T_{min}$ after	$Q = \Delta T / T_{mean}$ after
Healthy (H)									
1	Male	33.6	21.9	34.3	23.2	32.8	20.4	2.8	0.13
2	Male	32.3	24.7	33.3	25.7	29.9	22.6	3.1	0.13
3	Male	32.3	26.7	32.9	28.4	31.6	24.6	3.8	0.14
4	Male	33.4	27.9	34.6	29.8	32.9	26.8	3	0.11
5	Male	33.2	27.6	34.1	28.5	32.4	25.6	2.9	0.11
6	Male	29.7	27.2	30.7	28.3	27.5	26.1	2.1	0.08
7	Male	32.9	27.7	33.9	28.6	32.2	27	1.7	0.06
8	Male	33.1	22.9	34.1	26.3	32	20.9	4	0.17
9	Male	33.3	25.5	34.2	26.6	31.4	22.7	3.8	0.15
10	Male	32.5	25.1	33.4	26	31.9	22.3	2.7	0.11
11	Male	32.3	27.5	32.6	28.4	31.5	25.3	3.1	0.11
Mean		32.60	25.88	33.46	27.25	31.46	24.03	**3.00**	**0.12**
SD		1.1	2.1	1.1	1.9	1.5	2.3	0.7	0.03
Patients with spondyloarthrosis (SP)									
1	Male	32.8	22.3	33.4	25.2	31.8	19.3	5.9	0.26
2	Male	30.6	24.9	31.5	27.3	30	20.7	6.6	0.27
3	Male	32.9	24.9	33.4	26.4	31.3	22.7	3.7	0.15
4	Male	32.8	26.1	34.1	28.8	31.6	24.4	4.4	0.17
5	Male	33	25	33.7	26.8	32.4	23	3.8	0.15
6	Male	32.7	23.8	33.6	25.3	31.6	22.1	3.2	0.13
Mean		32.47	24.50	33.28	26.63	31.45	22.03	**4.60**	**0.19**
SD		0.92	1.30	0.91	1.35	0.80	1.80	1.35	0.06
Patients with sciatica (S)									
1	Male	30.4	21.4	31.6	23	29.6	19.3	3.7	0.17
2	Male	33.8	23.6	34.2	25.5	32.5	21.8	3.7	0.16
3	Male	30.1	20.9	31.1	22.5	29.2	17.5	5	0.24
4	Male	33.7	25.4	34.2	26.5	33.1	24.7	1.8	0.07
5	Male	33.3	21.4	34.2	22.9	32.6	16.8	6.1	0.29
6	Male	31.2	21.1	31.8	22.8	30.6	17.9	4.9	0.23
7	Male	31.7	22.2	33.4	25.6	30.5	20.4	5.2	0.23

Table 1 continued

Temp./ °C	Gender	T_{mean} before cryotherapy	T_{mean} after cryotherapy	T_{max} before cryotherapy	T_{max} after cryotherapy	T_{min} before cryotherapy	T_{min} after cryotherapy	$\Delta T = T_{max} - T_{min}$ after	$Q = \Delta T / T_{mean}$ after
8	Male	34.4	23.5	34.9	26.7	33.4	21.5	5.2	0.22
9	Male	32.3	22.4	34	23.8	31.4	20.9	2.9	0.13
10	Male	33.1	22.3	33.7	24.3	32.4	20.9	3.4	0.15
11	Male	29.9	20.4	30.9	21.6	28.9	17.2	4.4	0.22
12	Male	32.5	20.3	33.8	21.9	31.5	19	2.9	0.14
13	Male	35.4	21.6	36.2	23.7	34.6	17.8	5.9	0.27
14	Female	31.5	22	32.5	23.5	30.2	19.2	4.3	0.20
15	Female	29.5	22	30.4	23.4	28.3	19.1	4.3	0.20
Mean		32.19	22.03	33.13	23.85	31.25	19.60	**4.25**	**0.19**
SD		1.77	1.34	1.66	1.58	1.84	2.13	1.19	0.06
Patients with ankylosing spondylitis (AS)									
1	Male	32.9	27.1	33.4	28.1	32.4	25.2	2.8	0.10
2	Male	34.1	26.8	34.6	27.7	33.6	24.7	3	0.11
3	Male	33	24.7	33.9	26.9	32.1	23.6	3.3	0.13
4	Male	33.5	25	34	26.8	32.7	23.2	3.6	0.14
5	Male	32.3	24	34.4	26.8	30.2	19.4	7.4	0.31
6	Male	33.5	23.5	34.4	25.9	32.8	21.5	4.3	0.18
7	Male	33.6	23	34.2	24.9	32.8	19	5.9	0.26
8	Male	33.7	26.5	34.3	28.1	32.9	23.3	4.8	0.18
9	Male	33.2	22.7	34.1	25.7	32.6	20.5	5.2	0.23
10	Male	33	25.1	33.7	27.7	32.2	22.3	5.4	0.22
11	Male	33	25.9	33.5	28.2	32.4	24.7	3.6	0.14
12	Male	31.9	23.2	33.6	24.5	30.4	22.2	2.4	0.10
13	Male	30.6	21.5	32	23.4	29.5	19.3	4.1	0.19
14	Male	33.5	27.1	34.3	30.4	32.6	25.8	4.5	0.17
15	Male	32.6	22.8	33.6	25.2	31.5	20.2	5	0.22
16	Male	34.3	27	35.3	31.7	33.6	25.4	6.4	0.24
17	Male	33.8	26.4	34.5	29.3	33.2	25.1	4.1	0.16
18	Male	31.9	22.4	32.6	25	31.1	20	4.9	0.22
Mean		33.02	24.71	33.91	27.02	32.14	22.52	**4.48**	**0.18**
SD		0.91	1.87	0.76	2.14	1.16	2.35	1.30	0.06

Bold values refer to all statistical analysis

but also in the case of SP. It follows from our studies that temperature plots along as well as perpendicular to the spine can be useful in the medical diagnosis also.

The statistical outlines were performed for all studied groups. Different temperature parameters: mean, maximum and minimum temperature characterizing the spinal column in the range from Th1/Th2 to L5/S1 were taken into consideration (Table 1).

It follows from our analysis that mean temperature as well as maximum or minimum temperature seem to be not an adequate parameter because it depends on the number of cryotherapy sessions taken, the patient state of health and also the individual sensitivity of patient body cooling. Therefore, the contrast temperature $\Delta T = T_{max} - T_{min}$ and new relative contrast ratio $Q = (\Delta T)/(T_{mean})$ were

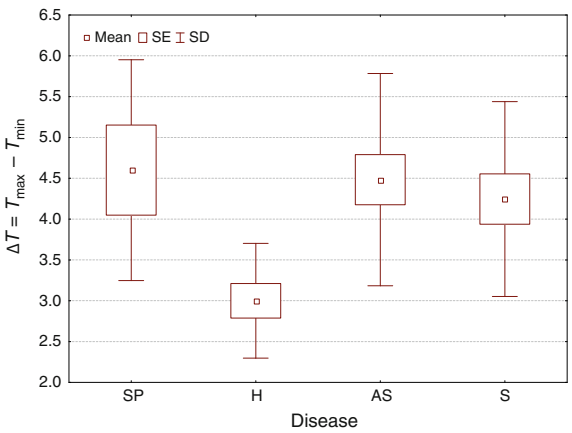

Fig. 5 Changes of $T_{max-min}$ obtained after whole body cryotherapy for all studied groups of patients

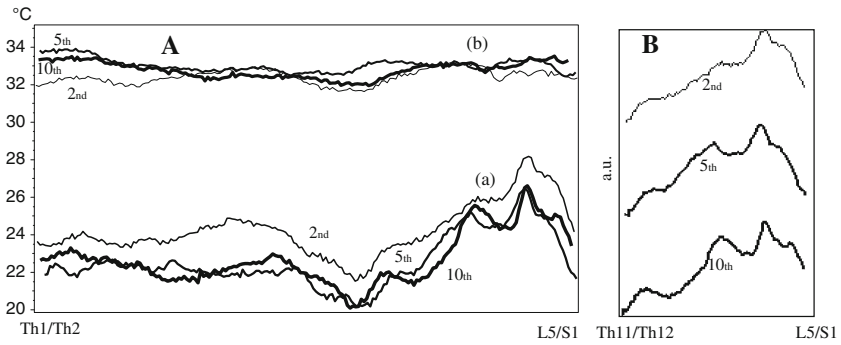

Fig. 6 **A** The plots of temperature characterizing spinal column in the range of vertebras from Th1/Th2 to L5/S1 for patients with spondyloarthrosis (SP), performed before (*b*) and after (*a*) cryotherapy in second, fifth and tenth day of rehabilitation cycle. **B** presents temperature plots in the range Th11/Th12 to L5/S1 performed after body cooling

introduced. Changes of ΔT calculated after whole body cryotherapy for all studied groups of patients are shown in Fig. 5. It is noteworthy that the difference between maximum and minimum temperature registered along the spine is about 3 °C for a healthy (H) while for people with spine pathological states (spondyloarthrosis—SP, sciatica—S and ankylosing spondylitis—AS) it is markedly larger (4.5 °C). Statistically significant differences of ΔT between healthy people and patients with spine diseases were obtained ($p = 0.01$).

Moreover one can see (Table 1) that the relative contrast ratio Q increases about 50% when patients suffering from spinal diseases are compared with healthy patients. This parameter confirmed observed changes of temperature with respect to mean temperature connected with the state of spinal cord health.

In our opinion, in order to become independent of the conditions of cryotherapy (body cooling), the contrast temperature and relative contrast ratio should be more proper in thermal characteristics of back pain diseases.

The aim of our investigation was also to monitor the effects of cryotherapy on spinal diseases during whole rehabilitation cycle.

Figure 6 shows temperature plots after cryotherapy in the second, fifth and tenth day of cryotherapy cycle. The anomal behaviour of temperature connected with diseases states is observed during the whole therapy cycle. However, if we focus on the temperature plots considered as a function of time (Fig. 6B), it is possible to get more information. Deeper analysis suggests that a wide peak connected with the inflammatory state in the lower lumbar region observed in the second day of cryotherapy becomes more clear and reveals the diseased vertebrates in details (perhaps because of the shrink of adjacent areas). On the other hand, the calculated factors ΔT, $\Delta T/T_{\mathrm{mean}}$ for each patient as well as for statistical groups (AS and S) did not show significant differences along with number of cryotherapy sessions although people reported decrease in pain and increase in fitness [22, 23].

Conclusions

The results of our work showed that the thermal imaging perform during whole body cryotherapy has a potential diagnostics value in the case of SP, AS and sciatica diseases.

The temperature plots performed along as well as perpendicular to lines in the spine as well as a temperature contrast or a relative change of contrast ratio seems to be useful in thermal diagnostics.

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