fizjoterapia polska
nr 3/2016 (16)

Porównanie zabiegu krioterapii miejscowej z zastosowaniem ciekłego azotu i dwutlenku węgla

Comparison of the Local Cryotherapy Treatment with the Application of Liquid Nitrogen or Carbon Dioxide

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Streszczenie

Cel pracy. Celem badania było porównanie temperatury powierzchownej skóry w zabiegach krioterapii miejscowej z użyciem dwutlenku węgla i par ciekłego azotu.
Materiał i metody. Badanie wykonano w Pabianickim Centrum Rehabilitacji na przełomie 2014/2015 roku w 52- osobowej grupie zdrowych ochotników obojga płci w przedziale wiekowym 20-36 lat, którą poddano jednorazowemu zabiegowi krioterapii miejscowej. Respondenci zostali podzieleni na dwie grupy B i P. W grupie B jako czynnik chłodzący wykorzystany został dwutlenek węgla, w grupie P pary ciekłego azotu. Wykonano rejestrację termowizyjną temperatury powierzchownej skóry przed krioterapia, bezpośrednio po oraz 2 minutach po niej.
Wyniki i wnioski. Porównanie otrzymanych wyników w obu grupach wskazują, iż wyższy stopień obniżenia temperatury wykazała krioterapia z użyciem dwutlenku węgla. Wystąpił odruch konsensualny w ręce przeciwnej.

Słowa kluczowe:

Krioterapia miejscowa, pary ciekłego azotu, dwutlenek węgla, termowizja

Abstract

Goal. The aim of the study has been to compare the temperature of the skin surface during the local cryotherapy treatment using carbon dioxide and liquid nitrogen vapor.
Materials and Methods. The study has been carried out in the Pabianice Rehabilitation Center, at the turn of the year 2014/2015, with the group of 52 healthy volunteers of both genders, 20-36 years old, who have been subjected to an one time cryotherapy treatment. The participants have been divided into two groups, marked as B and P. In Group B carbon dioxide has been used as the refrigerant, while in Group P it has been the liquid nitrogen. We have recorded, by means of thermography, the temperature of skin surface before the cryotherapy treatment, immediately after it and after 2 minutes time.
Results and Conclusions. The comparison of the results obtained in both groups indicates, that it is the carbon dioxide, that lowers the temperature, in cryotherapy, to a greater degree. There has been the consensual response in the other hand.

Key words:

Local cryotherapy, liquid nitrogen vapors, carbon dioxide, thermography

Introduction

Cryotherapy is a method of treatment, which uses impulses stimulating the surface cryogenic temperatures, within the range of -180°C to-110°C, in order to utilize the physiological and systemic responses to cold to support the healing process [1]. Cryotherapy is the basis for the cryo-rehabilitation. Immediately after each cryotherapy treatment, I administer a kinesiotherapy procedure to reinforce the beneficial effects, which have been obtained during the application of low temperatures. The inflammatory processes are being reduced and the skeletal muscles relax. In addition, this treatment allows to reduce pain, improve the patient's mood, and thus results in the greater commitment and readiness of the patients to perform movements. This in turn leads to the greater range of motion in the joints, significant intensification and the extended time of the kinesiotherapy exercises [2, 3, 4]. Nowadays the cryotherapy is being applied in treatment of many diseases, and in the form of cryo-stimulation, it may also be applied in healthy persons [5]. Cryotherapy causes in the human body a number of beneficial physiological phenomena. The most important among these include the analgesic effect. It comes from the elimination by the cold the sensory receptors and their connections with the proprioceptors in the sensory fibers. The ease in pain sensation partially confirms the "gate control theory", in respect of the mechanisms of the central nervous system. According to the gate control theory, presented in 1960s by Mellzack and Wall, stimulation of fibers A (fast conducting) causes the presynaptic inhibition of impulses being conducted from pain receptors via fibers C (slow conducting), the pain impulses are being inhibited in the dorsal horns of the spinal cord [6]. The cryogenic temperature works on the layer below papillary, where there are the end-bulbs of Krause - they react each time when the skin temperature is lowered. The threshold stimulus is a drop in temperature by 0.0040C per second within, the range of 10-41°C. Receptors reacting to temperature increase are the Ruffini corpuscles located deeper in the skin. Increase of 0.0010C per second, within the range of 20-45°C, is being caught by these receptors. A condition for receiving the impulses regarding the increase or decrease in temperature, is the difference which must occur between the surface of the skin and the ambient temperature. In the case there is no difference in temperatures, the phenomenon of physiological zero occurs, and receptors are not being stimulated [7]. Cold receptors is ten times more numerous (some 250 000) than heat receptors (some 30 000). On 1 cm^2 of skin there are approximately 2 heat receptors and 12 cold receptors [8].

Human beings, as the homothermal creatures, for proper functioning must maintain the internal temperature at a constant level, between 36-40°C. The temperature inside the cranial cavity, abdominal cavity, chest and other organs, and the blood temperature remains at the level of some 37°C, also during cryotherapy procedures. At the same time the surface layers of the skin and the extremities are poikilothermic, their temperature changes as the microcirculation there is different [8, 9]. The Dastre Morat Law says, that the thermal stimuli affecting a large area of skin cause the opposite reactions in

the large vessels of the abdominal and chest cavities to those in the skin vessels. The vessels of the spleen, kidneys and the brain exhibit the behavior same as the vessels of the skin.
The authors of the Polish publications on cryotherapy, most often choose the liquid nitrogen vapors for the cooling medium, which is primarily due to the fact, that this is the cryogen refinanced by the Polish National Health Fund [Narodowy Fundusz Zdrowia (NFZ)]. After reviewing the appropriate regulation of the President of the National Health Fund, one cannot help but wonders, why the local cryotherapy treatment with the use of carbon dioxide has been crossed out from the list of the refinanced procedures. This particular selection does not seem to be justified. In my study I have compared the treatments carried out with the use of liquid nitrogen and carbon dioxide, and the difference in the temperature change obtained during the procedures with each of cryogens applied.

Local Cryotherapy with Carbon Dioxide
Cryotherapy devices powered by carbon dioxide allow easy and safe local cryotherapy treatments. The processes taking place in the devices powered by a carbon dioxide are expansion and condensation of the gas. The adiabatic expansion involves a significant drop in the gas temperature. There occurs the so-called throttling, or squeezing of the gas from the area with higher pressure to the area with lower pressure. These phenomena have enabled the construction of the cooling applicators, which expand the CO_2 delivered via a narrow capillary tube, lowering its temperature to approximately -70°C [5]. The carbon dioxide, unlike any other refrigerants, affects the human body in two ways: physically – by cooling the surface of the skin it causes narrowing of blood vessels; biochemically – causes quicker vasodilation and supports the hyperemic reaction [5].

Local Cryotherapy with Liquid Nytrogen
In the devices using liquid nitrogen, there occurs the phenomenon of transformation from the liquid phase to the gas phase. Liquid nitrogen has a high evaporation heat level with a low boiling point of -195,8°C. In the end section of the applicator, the liquefied gas evaporates, while taking up the heat from the environment. This causes a rapid cooling off of the refrigerating surface of the applicator, and its temperature may even drop down to -195,8°C [5]. There are devices which work with a heater and those without a heater - operating with the pneumatic system. In the first kind the nitrogen vapors are provided by the heater. The greater is the power supplied to the heater, the blowing force is proportionally increased. In the pneumatic devices, to a container with liquid nitrogen, via a special pump, there is supplied a stream of warm air from environment (ca 20°C). And to obtain the vapors - a physical property of liquid gases is used, which is called the heat of vaporization (amount of energy required for the evaporation of a unit of mass of the substance, at constant pressure and temperature). By utilizing the heat of the nitrogen vaporization it is possible to operate the device with approx. 40% savings of the gas, which directly translates into significant cost reduction. One tank of a liquid nitrogen may be used over a longer period of time or for a larger number of

treatments. An additional advantage of this solution is the reduction of energy consumption, since the pneumatic pump uses only 86 W in comparison with 500 W used by the heater. Blowing power is regulated by the amount of air supplied to the tank. The first pneumatic version was manufacture by the Rolls Cryoflex company. The device includes a tank with liquid nitrogen, the so called Dewar Vacuum Flask, with the capacity from several to some dozen liters. Depending on the particular type, inside of the box there can be placed an electric heater, which serves to evaporate the nitrogen to overheat the vapors accumulated above the liquid. Skin contact with a drop of the liquid could cause a frostbite. Security measure to prevent spillage of the drops of liquid nitrogen is the, which gets activated when the temperature goes below 95 K. Temperature of 100 K means, that the device i ready to use. The temperature of the going out gas is being regulated by a throttle valve. The dry nitrogen vapor is being transferred to the cryo-aplicator via a flexible cryogenic pipe and blown directly to the desired spot on the patient's body. To achieve the optimum result, there is the possibility to adjust the distance from the cryo-applicator, blower power and the duration of the treatment. Mist visible at the outlet of the nozzle is a condensed steam, and its density depends on the temperature and humidity of the ambient air. Nitrogen is not a toxic gas, but it is released into the atmosphere and thus reduces the amount of oxygen in the air. Therefore it is very important, to carry out the cryotherapy treatments in well ventilated spaces. Cold nitrogen vapors are heavier than air, and therefore accumulate in the lower part of the room [5].

To precisely measure temperature, when cooling the particular part of the body, often the thermovision cameras are used, as they allow for a quick, non-contact and precise estimation of any temperature changes. These devices are being used not only to develop the diagnostic methods but also to verify the effects achieved in the procedure [1]. This test allows to perform measurements of the patient's body part surface temperature. By the means of thermography it is possible to estimate the temperature changes after the treatment (ca 10-12°C in a healthy person and ca 20°C in an ill person), to observe the temperature changes in a longer perspective [8].

Materials and methods

The study has been conducted in Pabianice Rehabilitation Center, at the turn of 2014 and 2015, on a group of 52 healthy, young volunteers. All the relevant research criteria have been fulfilled, while taking under consideration any contraindications. The research participants have been informed about the goal of the study, and have expressed their informed consent to participate in it. In accordance with the cryogen used, the participants have been divided into two groups. The Test Group "B", consisting of 24 persons, has undergone the cryotherapy using the carbon dioxide. The Control Group "P", consisting of 28 persons, has undergone the cryotherapy using the liquid nitrogen.

To properly describe the research material and get answers to the research questions, there has been applied a onetime local cryotherapy treatment and the thermovision assessment, according to the specially designed methodology. For the latter purpose we have used the Keithley 2010 multimeter camera. Prior

to cooling of the left forearm, we have taken some thermovision photographs. Then, the forearm was being cooled for 3 minutes, and during the treatment more images had been recorded. Next, more photographs have been taken immediately after the treatment and 2 minutes after the exposure. The same operation has been repeated on the right forearm. The temperature, in the case of Group "B", has been measured at the outlet of the nozzle and 2 cm from the device. In the case of Group "P", at the outlet of the nozzle and 2, 10 and 15 cm from it. The obtained numerical values (Table 1) have been analyzed statistically. Before the treatment, and until the end of the cryogen exposition, the examined person had been in a room with a constant temperature of 25,3°C and the relative humidity of 40-50%.

Table 1 Value of temperature in different measurement points

Measurement point	CO_2	N_2
Nozzle	-83ºC	-132ºC (144)
2 cm from outlet	-74ºC (78)	-121ºC (128)
10 cm from outlet		-70ºC
15 cm from outlet		-48ºC

The persons participating in the study have been properly prepared for the treatment. Images have been recorded in the perpendicular position of the camera to the surface of the body. The distance between the camera and the body has been between 100-125 cm. The acquired images have been processed statistically, to obtain answers to the research questions.
The statistical analysis has been carried out using the Statistica Software 10PL package. For the analysis of the data, the Student's t test has been used. In verification of the hypotheses, the significance level of p = 0,05 has been applied.

Results

The left hand has been cooled down and its temperature measured before, immediately after and 2 minutes after the treatment. Before the treatment, the hand temperature in both groups did not differ in a statistically significant way.
Immediately after the treatment, a significant ($p < 0.001$) difference in the left hand temperature has been found. The temperature of the left hand in the group, where the cooling has been done with the use of liquid nitrogen, immediately after the treatment has amounted to 6.31°C, and in the group treated with the carbon dioxide it has been lower, and amounted to -0,88°C.
In the second minute after the treatment, the left hand temperature (15.2°C) in the group treated with the carbon dioxide was still significantly lower than the in the group cooled down with the liquid nitrogen (19,41°C) (Table 2, Fig. 1). The results have also shown the consensual effect, with the lowering of temperature in the right forearm.

Table 2 Comparison of temperatures of the left hand, between the groups, in the subsequent examinations before, immediately after and 2 minutes after the treatment

Examination	Group	Left hand temperature [ºC] Number	Mean	SD	Me	Min	Max	T-student test
Before treatment	N_2	28	31.89	0.73	31.90	30.90	33.30	p=0.091 (NS)
	CO_2	24	32.26	0.83	32.60	31.00	33.30	
Immediately after treatment	N_2	28	6.31	2.40	5.30	3.50	9.70	p<0.0001
	CO_2	24	-0.88	0.45	-1.05	-1.60	-0.30	
2 minutes after treatment	N_2	28	19.41	1.93	18.90	16.90	23.20	p<0.0001
	CO_2	24	15.20	4.15	14.40	9.30	22.60	

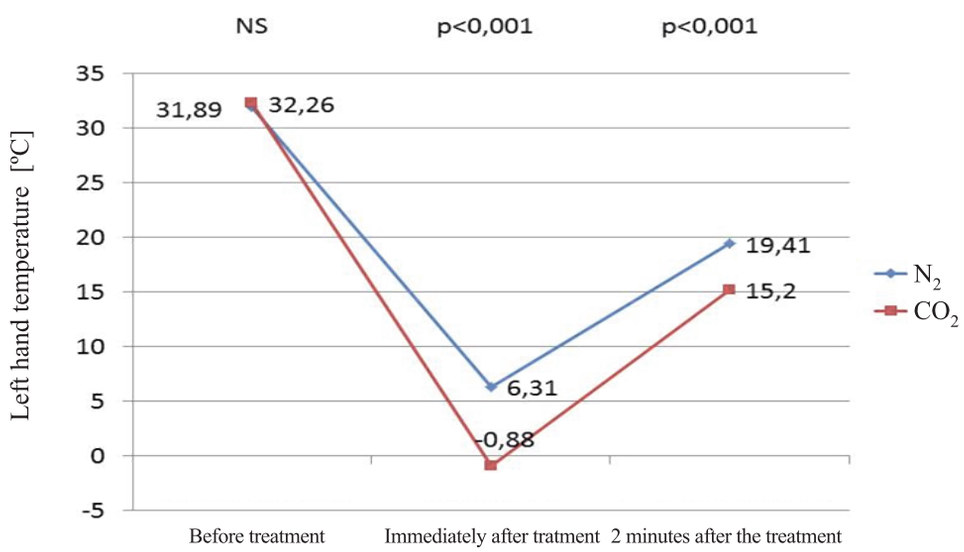

Fig. 1. Comparison of temperatures of the left hand, between the groups, in the subsequent examinations before, immediately after and 2 minutes after the treatment

Both, in the group cooled down with the use of nitrogen and the group treated with the carbon dioxide, in 2nd minute after the treatment, the temperature has decreased significantly ($p < 0.001$) (Table 3. Fig. 2).

Table 3. Comparison of temperature of the left hand before and in the 2nd minute after the treatment, in both examined groups

Group	Examination	Number	Left hand temperature [ºC]					T-student test
			Mean	SD	Me	Min	Max	
N_2	Before treatment	28	31.89	31.89	31.90	30.90	33.30	p<0.0001
	2 minutes after treatment	28	19.41	19.41	18.90	16.90	23.20	
CO_2	Before treatment	24	32.26	32.26	32.60	31.00	33.30	p<0.0001
	2 minutes after treatment	24	15.20	15.20	14.40	9.30	22.60	

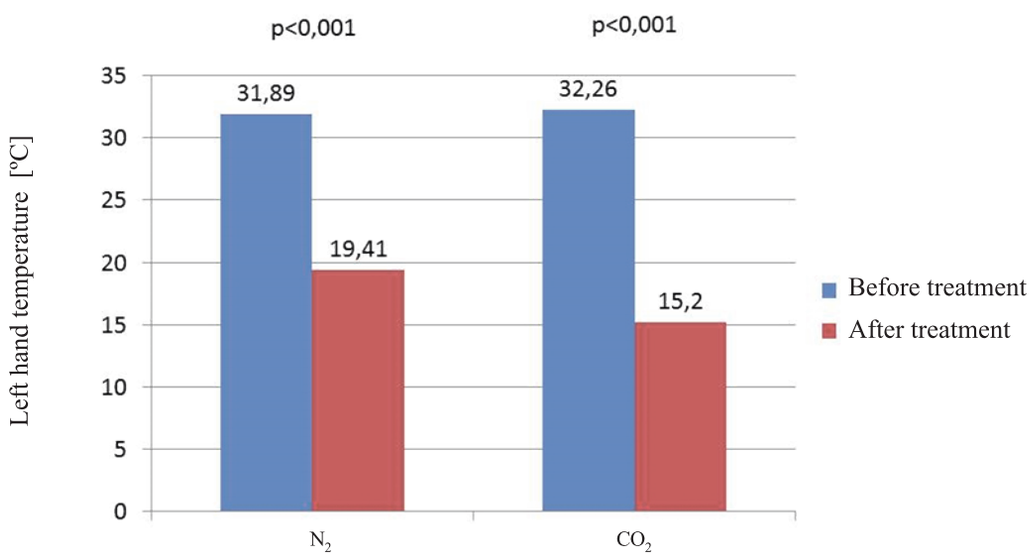

Fig. 2. Comparison of temperature of the left hand before and in the 2nd minute after the treatment, in both examined groups

Immediately after the left hand has been cooled down, the cryotherapy treatment has been to the right hand in both examined groups. The temperature of the right hand right before the treatment did not differ significantly, between the groups, cooled down with the liquid nitrogen and the carbon dioxide. In the second minute after the treatment, also there have not been found statistically significant differences between the two groups (Table 4. Fig. 3).

Table 4. Comparison of temperatures of the right hand, between the groups, in the subsequent examinations before and in 2 minutes after the treatment

Examination	Group	Number	Right hand temperature [ºC]					T-student test
			Mean	SD	Me	Min	Max	
Before treatment	N_2	28	32.07	0.69	32.10	31.00	33.30	p=0.454 (NS)
	CO_2	24	32.26	1.11	32.55	30.80	33.80	
2 minutes after treatment	N_2	28	32.04	0.78	31.90	31.40	33.80	p=0.147 (NS)
	CO_2	24	31.68	1.00	31.75	30.50	32.90	

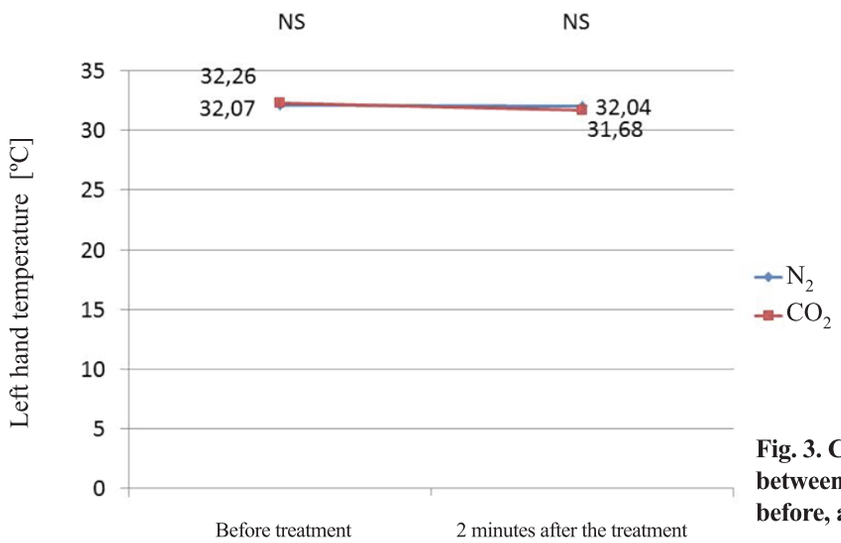

Fig. 3. Comparison of temperatures of the right hand, between the groups, in the subsequent examinations before, and in 2 minutes after the treatment

The temperature of the right hand, before the treatment of cooling down with the nitrogen, was 32,07°C and in the second minute after the treatment it was 32,04°C. In this group, there were no significant differences found between the examinations.
The temperature of the right hand, before the treatment of cooling down with the carbon dioxide, was 32,26°C and in the second minute after the treatment it was 31,68°C, and has been statistically significantly (p<0,001) lower (Table 5, Fig. 4).

Table 5. Comparison of temperature of the right hand before, and 2 minutes after the treatment, in both examined

Group	Examination	Number	Temperatura ręki prawej/Right hand temperature [ºC]					T-student test
			Mean	SD	Me	Min	Max	
N_2	Before treatment	28	32.07	0.69	32.10	31.00	33.30	p=0.681 (NS)
	2 minutes after treatment	28	32.04	0.78	31.90	31.40	33.80	
CO_2	Before treatment	24	32.26	1.11	32.55	30.80	33.80	p<0.001
	2 minutes after treatment	24	31.68	1.00	31.75	30.50	32.90	

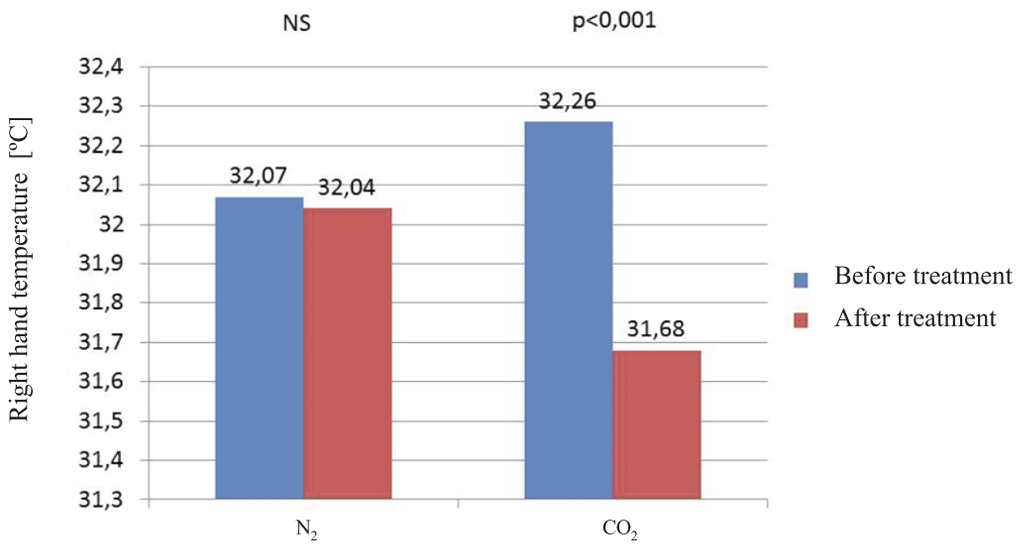

Fig. 4. Comparison of temperature of the right hand before, and 2 minutes after the treatment, in both examined groups

The temperature difference has been calculated between this in the examination performed before the treatment and in the 2nd minute after the treatment, for left and right hand, in both examined groups. The temperature differences in left hand have been statistically significant ($p < 0.001$), between the two groups. The temperature difference of the left hand in the group, where the cooling has been done with the use of liquid nitrogen, in 2nd minute after the treatment amounted to 12,47°C, and in the group treated with the carbon dioxide it has been significantly higher, and amounted to 17,06°C.
The temperature difference of the right hand in the group, where the cooling has been done with the use of liquid nitrogen, in 2nd minute after the treatment amounted to 0,03°C, and in the group treated with the carbon dioxide it has been significantly higher ($p<0,001$), and amounted to 0,58°C. 6. Fig. 5).

Table 6. Comparison of changes in hand temperature in the examined groups, on left and right side

Hand	Changes of temperature between test before treatment and 2 minutes after treatment [°C]							T-student test
	Group	Number	Mean	SD	Me	Min	Max	
Left	N_2	28	32.07	0.69	32.10	31.00	33.30	p=0.454 (NS)
	CO_2	24	32.26	1.11	32.55	30.80	33.80	
Right	N_2	28	32.04	0.78	31.90	31.40	33.80	p=0.147 (NS)
	CO_2	24	31.68	1.00	31.75	30.50	32.90	

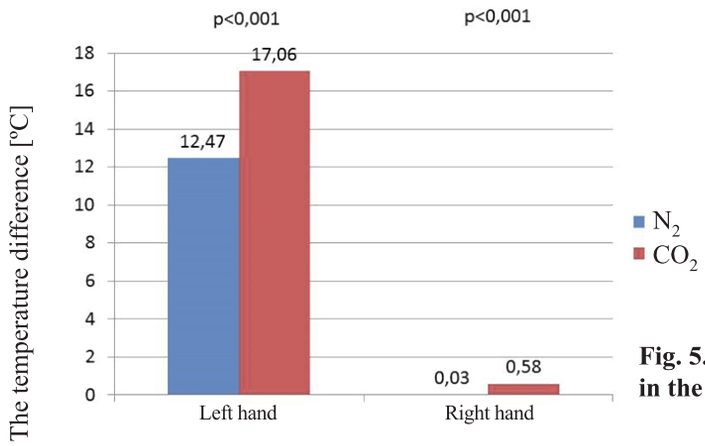

Fig. 5. Comparison of changes in hand temperature in the examined groups, on left and right side

Both, in the group cooled down with the liquid nitrogen, and the group treated with the carbon dioxide, there have been determined statistically significant ($p < 0.001$) changes between the temperature before the treatment, and in 2nd minute after the treatment, between the left and right hand. In both groups, the temperature change between the examinations has been significantly higher in the left hand than in the right hand (Table 7. Fig. 6).

Table 7. Comparison of changes of the temperature measured before the treatment and in 2nd minute after the treatment, between the right hand and the left, in both examined groups

Group	Hand	Number	Changes of temperature between test before treatment and 2 minutes after treatment [°C]					T-student test
			Mean	SD	Me	Min	Max	
N_2	N_2	28	12.47	1.52	12.00	10.10	15.00	p<0.0001
	CO_2	28	0.03	0.36	0.00	-0.50	0.60	
CO_2	N_2	24	17.06	3.60	18.40	9.80	21.90	p<0.0001
	CO_2	24	0.58	0.40	0.50	0.00	1.30	

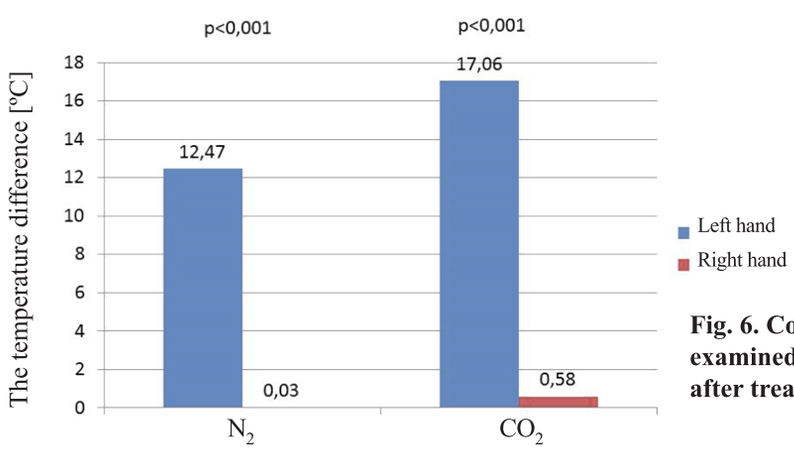

Fig. 6. Comparison of changes in hand temperature in the examined groups, before the treatment and 2 minutes after treatment

Discussion

Contemporary literature brings many reports on the subject of cryotherapy and its effects. As the most important effects are being listed: analgesic, anti-inflammatory, stimulating and improving the general fitness. There is a fairly wide variety of equipment for cryotherapy, using as the refrigerant: carbon dioxide, liquid nitrogen vapors or just cooled down air. In this study we have tried to compare of the performance of the carbon dioxide and the liquid nitrogen vapors. Our own research has shown, that not only the temperature at the outlet of the nozzle is important, but also the distance between the nozzle of the device and the surface of the skin. Although at the outlet of the nozzle, the carbon dioxide temperature is higher, -83°C (for comparison, in the case of the liquid nitrogen it is -132°C), on the contact with the patient's skin its value is lower, -74°C, while with the liquid nitrogen vapors it amounts to -48°C. This is due to the fact, that the distance from the surface of the body with the CO_2 equals 5 cm, while the treatment with the liquid nitrogen vapors is being performed from a distance of some 15-20 cm. Another issue, which should be addressed, is the cost of a single treatment and the cryogens storage. What should be considered, are the losses incurred by any institution using the cylinders with liquid nitrogen, which tends to escape, and the higher costs of the liquid nitrogen delivery.

Published studies concern both, the general and local impact. The cryotherapy studies carried out by Podbielska et al. [5] on 240 healthy persons have shown, that both the time and the cryogen temperature are important. The effects of the longer time of the refrigerant application, have been the lower body temperature, and the extended time of returning to the original body temperature. The temperature distribution depends on the adipose tissue and muscle tissue ratio (muscle tissue and skin better conduct the heat than the adipose tissue), but also on the individual body properties. The results of the temperature measurements of the lower extremities have shown the greater decrease in their temperature, in comparison with the upper extremities and the trunk. This may however be a result of the temperature distribution in the cryogenic chamber. The results obtained by Piechura et al. [10] who in their research, as a source of low temperature, used the carbon dioxide, have shown significant improvement of the mobility of shoulder after the cryotherapy. They have also stressed the importance of the kinesiotherapy. Wilk et al. [1] have also observed the faster return of the cooled down body part to the original temperature, if immediately after the cryotherapy procedure the kinesiotherapy has been applied. Woszczak et al. [11] have determined the cryotherapy treatment as save also for the children with the cerebral palsy. The research has been carried out using the liquid nitrogen at the temperature of -196°C, measured at the outlet of the nozzle. Change of the average value of the temperature, measured by the means of thermovision in the lower right extremity, at the beginning of the 28 days of the patient's stay, has been 7.1°C, and at the end of of the period -10.1°C. The temperature drop of the left lower extremity, before the period of stay, has been 8.9°C , and on the last day of the stay, the difference has been 11.4°C. The authors have demonstrated this way, the ability to adapt the cardio-vascular system of the lower extremities and to reduce the spasticity in children with the cerebral palsy. Reduction of the spasticity also have shown Gregorowicz et al. [8] who have carried out the general cryotherapy treatment in the group of 23 persons diagnosed with the multiple sclerosis. In our study the average temperature of the left hand in the group, where the cooling has been done with the use of liquid nitrogen, immediately after the treatment has amounted to 6.31°C,

and in the group treated with the carbon dioxide it has been lower, and amounted to -0,88°C.. In the second minute after the treatment, the left hand temperature in the group where the refrigerant has been the carbon dioxide, amounted to 15.2°C, while the temperature of the left hand cooled down with the liquid nitrogen has been 19.41°C. The two-minutes treatment with the liquid nitrogen vapors, carried out by Szpotowicz et al. [12] on healthy subjects, has shown a reduction in the sensory excitation level of the cutaneous nerve. This effect has lasted for approximately 20 min. Giemza et al. [7] in their study evaluating the efficacy of the general cryotherapy in combating the lower back pain have shown, that the application of the cryotherapy treatment twice a week is not sufficient to achieve the desired results.

Conclusions

1. Based on the analyses performed, it has been found that both, the local cryotherapy with the use of the carbon dioxide and the liquid nitrogen, do locally lower the human skin temperature.
2. A higher degree of the temperature reduction has been determined for the cryotherapy with the use of the carbon dioxide.
3. The consensual impact on the other hand has occurred.
4. Also has been observed the tendency to maintain longer the stimulating effect, after the treatments with the use of the carbon dioxide.

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