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CIRCADIAN RHYTHM OF CORE BODY TEMPERATURE (PART II): HYPERBARIC ENVIRONMENT INFLUENCE ON CIRCADIAN RHYTHM OF CORE BODY TEMPERATURE

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ABSTRACT

The aim of this study was to analyse dynamic fluctuations in the circadian rhythm of the core body temperature in healthy adults exposed to conditions in a hyperbaric chamber, using fully objective-telemetric measurement methods. The study group consisted of 13 healthy males (age 32±6.4 years, height 1.85±0.1 m, body weight 84.00±6.3 kg; BMI 24.7±1.2 kg/m^2). The core body temperature (CBT) was measured with the *Vital Sense* telemetry system. The volunteers were placed in a hyperbaric chamber, exposed to compression of 400 kPa, with the exposure plateau of approx. 30 minutes, followed by gradual decompression. The mean core temperature was 36.71°C when registered within 10 minutes before the exposure, 37.20°C during the exposure, 37.27°C one hour after the exposure, 37.36°C 2 hours after the exposure, and 37.42°C three hours after the exposure. The conducted observations show that one-hour stay in a hyperbaric chamber at a depth of 30 m results in an increase in the body temperature, particularly significant after the exposure ends, and maintained for at least 3 hours after the exposure.
Key words: circadian rhythm, body temperature, hyperbaric.

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INTRODUCTION

Changes in the core body temperature are influenced by numerous factors, both endogenous, in the form of physiological and pathophysiological mechanisms, and exogenous. Circadian or infradian rhythms, or biological age are examples of endogenous factors [1].

Many authors report a strongly modulating influence of environmental factors on homoeostasis, including the hyperbaric environment. Depending on exposure time and type, a diver is exposed to various physical factors including, first of all, high hydrostatic pressure, physical and chemical effects of a respiratory agent, and low ambient temperatures.

Interfering agents associated with the effect of the hyperbaric environment on the human body include: the toxic effect of oxygen, the narcotic effect of inert gases, decompression sickness, the abnormal functioning of some sensory systems (in particular sight, somatosensory and vestibular systems), and hypothermia [2,3].

Effectively functioning regulation and adaptation mechanisms in the divers body should counterbalance the effects of stress agents associated with staying in hyperbaric conditions. In the available literature there are no reports on changes in the core body temperature occurring in a diver's body exposed to conditions in the hyperbaric chamber, i.e. excluding the influence of water temperature on thermoregulatory processes.

The aim of this study was to analyse dynamic fluctuations in the circadian rhythm of the core body temperature in healthy adults exposed to conditions in a hyperbaric chamber, using objective and modern measurement methods.

MATERIAL AND METHODS

Study group

The study group consisted of 13 healthy men. Apart from giving a voluntary informed consent to participation in the study, the main enrolment criteria included being of the male sex, an absence of diseases and the possession of the correct body mass (BMI: 18.5- 24.99 kg/m^2). Exclusion criteria included: an active or chronic disease and taking any medicines throughout the study. The basic biological parameters of the studied group are characterised in Table 1.

Tab. 1

Basic biological parameters of studied group.

Parameter	Studied group (n= 13)
	mean ± SD
Age, years	32±6.4
Body height [cm]	179±8.7
Body weight, [kg]	83.4±14.7
BMI, [kg/m^2]	25.9±3.5

Vital Sense – telemetric measurements of the core body temperature

In the subjects the core body temperature (CBT) was measured with the Vital Sense telemetry system from Mini Mitter, currently Philips Respironics (Vital Sense, Mini Mitter Co. Inc., Bend Oregon, USA). The system consists of two components: a mobile recording display storing and exporting digital data for measured temperature values, and a telemetric capsule - Core Body Temperature Capsule (CBTC) (Fig. 1).

The telemetric capsule transmits the measured core body temperature values by radio. The telemetric system consists of an internal thermistor and of an external cover made of plastic adapted to medical applications. A study subject swallows the capsule with a small amount of warm water. After approximately one minute the capsule starts measuring the body's core temperature and emitting a radio signal at 15 second intervals; the display saves an average value of four successive measurements. The registered and transmitted values of the core temperature are saved in the display's internal memory. The telemetric capsule is resistant to digestive enzymes, and excreted without any side effects or effect on the gastrointestinal tract function.

Exposure characteristics

The volunteers were placed in a hyperbaric chamber and exposed to a compression of 400 kPa. The exposure plateau was equal to approx. 30 minutes, and followed by gradual decompression in accordance with the decompression tables of the Polish Navy (Table 2).

For safety reasons, to minimise the risk of side effects – "bends", the decompression pattern used following the exposure to 400 kPa (0.4 MPa–0.3 MPa + 0.1 MPa atmospheric pressure) was the same as after diving at 33 meters, which corresponds to the pressure of 440 kPa. Air was the breathing gas used during all dives in the hyperbaric chamber.

Tab. 2

Decompression chamber following exposure at 30 m below sea level (bsl).

Exposure (m bsl)	Plateau (min.)	Decompression stop depth (m) / Time at a decompression stop (min.)			Overall decompression duration
33	30	9	6	3	35 minutes

Study protocol

To evaluate the effect of the hyperbaric environment on the core body temperature, a continuous monitoring of the core body temperature was started before subjects entered the hyperbaric chamber, and continued during one hour of exposure and for the following 24 hours (Fig. 1, 2).

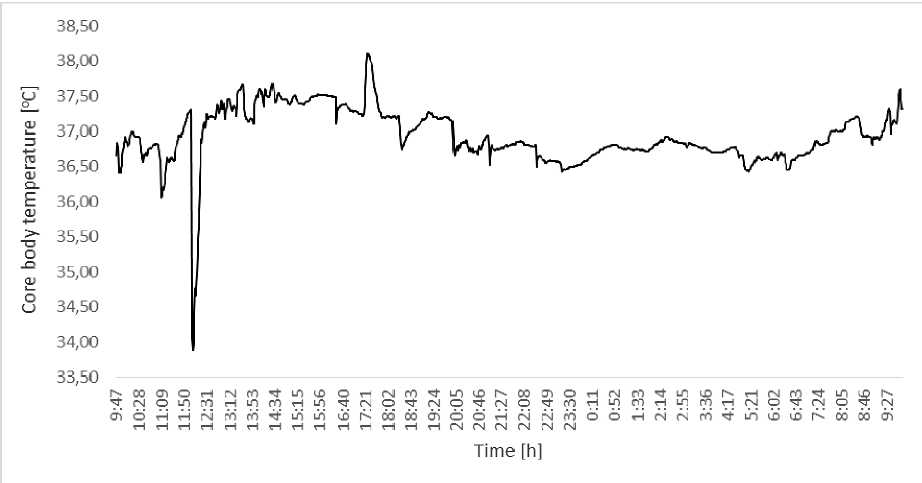

Fig. 1. An example of a 24 hour recording of the core body temperature in a diver exposed to conditions of the hyperbaric chamber.

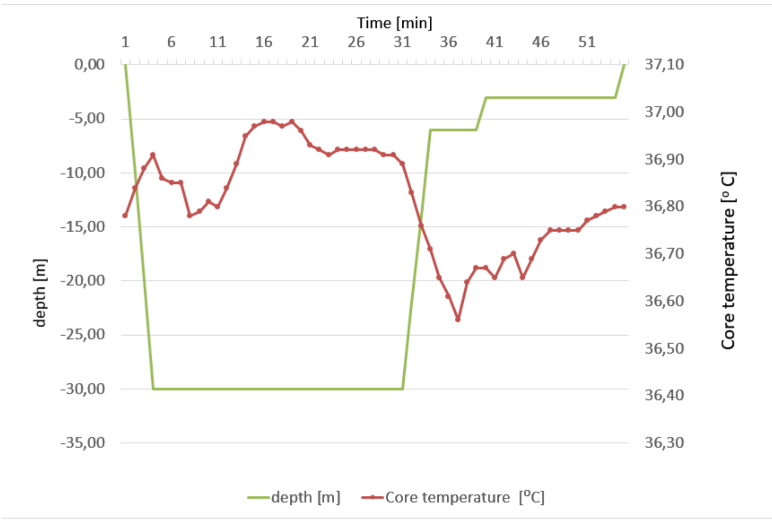

Fig. 2. An example of a recording of the core body temperature in a diver during exposure.

To obtain a detailed analysis of the dynamics of core temperature fluctuations, and avoid errors resulting from possible single and occasional anomalies appearing during temperature measurements, a specific form of analysis of core temperature measurements was applied. Signals obtained throughout the study were divided into 15-minute measurement intervals, for which the mean averages of measured core temperature were calculated and then analysed statistically.

For the purpose of this publication, a statistical analysis of 16 measurement intervals was presented (MI_01–MI_16), corresponding to: MI_01 – measurement taken 10 minutes prior to the exposure, MI_02–MI_05 – during the exposure, MI_06–MI_09 – one hour after the exposure, MI_10–MI_13 – 2 hours after the exposure, and MI_14–MI_16 – 3 hours after the exposure.

Statistical methods

The normality of variabilities distribution was evaluated with the *Shapiro–Wilk* test, and their statistical characteristics were presented as arithmetic means and standard deviations (±SD), as well as calculated minimum and maximum values. The results were analysed using the Friedman's test and Kendall rank correlation. All calculations were performed with the *Statistica 10* (StatSoft) package, with the assumed level of statistical significance of $\alpha<0.05$.

RESULTS

Values of the core body temperature obtained during exposure to the hyperbaric environment are presented in Table 3 (MI – measurement interval). The mean core temperature was 36.71°C, when registered within 10 minutes before the exposure, 37.20°C during the exposure, 37.27°C one hour after the exposure, 37.36°C two hours after the exposure, and 37.42°C three hours after the exposure.

Tab. 3.

Basic statistical parameters of registered changes in the core body temperature for all evaluated measurement intervals.

	N	Mean	Minimum	Maximum	Standard deviation
MI_01	13	36,92	36,71	37,20	0,15
MI_02	13	37,00	36,70	37,61	0,22
MI_03	13	37,13	36,69	37,77	0,27
MI_04	13	37,18	36,73	37,58	0,23
MI_05	13	37,24	36,76	37,66	0,25
MI_06	13	37,25	36,80	37,69	0,24
MI_07	13	37,24	36,76	37,73	0,26
MI_08	13	37,30	36,93	37,72	0,21
MI_09	13	37,28	36,93	37,72	0,23
MI_10	13	37,32	37,02	37,72	0,18
MI_11	13	37,37	37,10	37,73	0,18
MI_12	13	37,36	37,12	37,74	0,17
MI_13	13	37,38	37,12	37,71	0,16
MI_14	13	37,42	37,20	37,69	0,13
MI_15	13	37,42	37,17	37,68	0,17
MI_16	13	37,43	37,07	37,64	0,18

Tab. 4

Absolute differences between mean MI_01 ranks and other measurement intervals (rank differences > 6.59, at the confidence level of < 0.05, were marked as *).

Measurement interval	MI_01
MI_01	---
MI_02	1,77
MI_03	2,69
MI_04	4,69
MI_05	5,61
MI_06	5,96
MI_07	6,04
MI_08	8,04*
MI_09	7,58*
MI_10	8,54*
MI_11	10,15*
MI_12	9,88*
MI_13	10,58*
MI_14	11,38*
MI_15	10,69*
MI_16	10,23*

During the study, significant differences in the core body temperature were noted between MI_01 and MI_08, MI_09, MI_10, MI_11, MI_12, MI_13, MI_14, MI_15, MI_16 (Table 3).

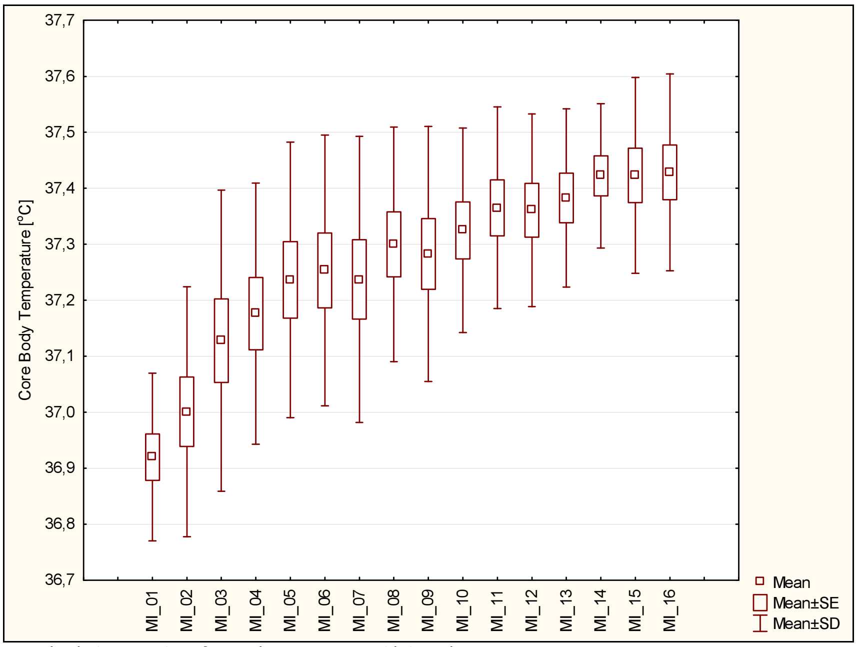

Fig. 3. Recorded changes in the core body temperature for each measurement interval.

DISCUSSION

Exposure to the hyperbaric environment changes the circadian rhythm of the core body temperature. The conducted observations show that a one-hour stay in a hyperbaric chamber at a depth of 30 m results in an increase in body temperature, particularly significant after the exposure ends, and is maintained for at least 3 hours after the exposure.

When the body adapts to the increased pressure in its environment, the core body temperature rises, resulting in an increased blood flow to tissues, facilitating gas exchange during the first phase of diving, the stay at 30 m bsl and removal of excessive amounts of gases when returning to normobaric conditions.

As the highest absorption of inert gases occurs during the first (and usually the deepest) stage of diving, this mechanism may significantly increase tissue perfusion. Ultimately, it may pose a risk of decompression disease during diving. Studies on repeated diving were conducted on Vancouver Island in British Columbia [4]. The divers wore wet suits, both well and poorly suited to the conditions. The water temperature was approx. 10^{o}C.

Using a Doppler ultrasound transducer, the researchers measured the presence and number of gas bubbles in the divers' blood. They observed lower levels of bubbles in divers dressed unsuitably. The researchers concluded that when a diver is cold before diving, constriction of blood vessels hinders blood flow in their limbs, resulting in turn in a limited absorption of inert gases. A lower absorption of inert gases led to their lower levels at the end of diving.

Previously, the available reports described the effect of water temperature on disrupted thermoregulation in divers. With decreasing water temperature, metabolic processes increase proportionally to a drop both in the core body and in skin surface temperature. In cold water vasoconstriction in the skin is triggered by a decrease in skin surface temperature. However, a drop in the core body temperature influences an increase in the activity of the sympathetic nervous system, resulting in vasoconstriction during prolonged exposure to cold [5,6].

Research results indicate that immersion in water of 32°C does not influence the core body temperature and metabolism, while immersion in water of 20°C significantly reduces the temperature and increases the metabolic rate by 93%; immersion in water of 14°C also reduces the temperature and increases the metabolic rate by 350% [7].

It was also indicated that nitrogen oxide is a specific mediator controlling changes in body temperature, particularly in terms of heat production, especially in the brown adipose tissue. Following stimulation of the sympathetic system, brown adipose tissue produces nitrogen oxide (NO) which possibly diffuses through the vascular bed and participates in thermogenesis processes [8].

The depth reached during diving is also a factor influencing heat stress through the hydrostatic pressure influence on the increased thermal conductivity. Mastuda et al. demonstrated that the thermal reaction, i.e. a reduction in the body temperature and the increased thermal conductivity was more pronounced in conditions of helium-oxygen at 11 ATA than in air at 1 ATA [9].

CONCLUSIONS

Hyperbaric exposure (in a hyperbaric chamber at a depth of 30 m) changes the circadian rhythm of the core body temperature in the form of a short-term increase in body temperature, which is particularly significant when the exposure ends, and is maintained for at least 3 hours after the exposure. The obtained results are possibly a consequence of the body's adaptive processes, as according to the gas laws, an increase in the core body temperature and better tissue perfusion facilitate removal of gases from tissues.

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