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Original scientific paper

Effects of a Hyperbaric Environment on Subcutaneous Adipose Tissue Topography (SAT-Top)

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ABSTRACT

The physiological reactions of the body in scuba diving situation can be simulated in a pressure chamber by increasing the ambient pressure. In this study the influence of a hyperbaric environment of 6 bar on the changes of the subcutaneous adipose tissue (SAT) thicknesses on different body sites in 68 voluntary men with undersea diving experience was investigated. Measurements of SAT-Topography (SAT-Top) were performed with the optical device Lipometer before and after hyperbaric exposure. We observed a significant increase of the SAT-layers of the upper body zones, upper abdomen (+24.5%), lower abdomen (+21%) and front chest (+19%) after hyperbaric exposure. This increase of volume can be assumed to the nitrogen accumulation in fat cells at increased ambient pressures. In conclusion we describe for the first time in detail the influence of a hyperbaric environment on quantitative and topographic changes of SAT.

Key words: *hyperbaric exposure, body fat distribution, lipometer*

Introduction

Pressure chamber therapy (=hyperbaric oxygen therapy) is used in a wide variety of medical conditions like osteomyelitis, carbon monoxid poisoning, necrotic wound healing, gas embolism or decompression sickness[1–5]. The scuba diving situation can be simulated in a pressure chamber by adapting the ambient pressure and it is of high interest to elucidate some special physiological reactions of the human body. A special attention is focused to the inert gas nitrogen (N_2) and its effects in a diving situation. The risks of diving are mainly caused by pressure changes of breathing air at submerging, staying in depth and decompression[5]. Underwater divers breath compressed air, absorb N_2 and eliminate it during and after decompression. A too rapid decompression may result in decompression sickness due to intra- and extravascular bubble formation[6]. As N_2 is dissolved in fatty tissue five times more than in water or blood, a higher fat content implies higher N_2 content in body tissue[7]. Tables of diffusion coeficients for N_2 as well as for other gases are available[8]. The high partial pressure of N_2 from depths of 30 m and more affects the function of cell membranes causing N_2 narcosis[9,10]. As replacing the N_2 in the breathing mixture with helium eliminates the narcotic effect, the expense and rarity of helium make it an impractical solution for general situations[11].

Body fat and the thicknesses of subcutaneous adipose tissue layers have been studied with several methods such as caliper, bioimpedance analysis, dual energy X-ray absorptiometry, and computed tomography[12–15]. These techniques lack precision (caliper) and entail the risk of radiation exposure (dual energy X-ray absorptiometry, computed tomography) and/or are expensive. The »lipometer« (EP no. 0516251) is an optical device that mea-

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sures the subcutaneous fat layer at any given site of the human body. It permits a noninvasive, quick, precise, and safe measurement of the thickness of subcutaneous adipose tissue. Technical details of the Lipometer and validation results using computed tomography and dual energy X-ray absorptiometry as reference methods have already been published[16–19]. The implement of the Lipometer measurement at fifteen specified body sites provides a subcutaneous adipose tissue topography (SAT-Top) which gives detailed information of an individual body fat distribution pattern[20–22].

The pressure chamber therapy is an intensive burden for the human body. The overpressure causes physiological reactions immediately occurring. As the absorption of N_2 in fatty tissue was expected, we hypothesised that the hyperbaric environment might expand the adipose tissue layers. The aim of our study was to investigate the quantitative and topographic SAT-distribution changes in men after hyperbaric exposure.

Subjects and Methods

Subjects

Sixty-eight male volunteers with undersea diving experience participated in this study. A complete physical examination, including chest x-ray and electrocardiogram, was done before the investigation. Standing height was measured to the nearest 0.1 cm using a portable calibrated stadiometer (SECA®-220, Hamburg, Germany). Body mass was measured to the nearest 0.01 kg using calibrated electronic scales (Soehnle® 7700, Murrhardt, Germany), BMI was calculated as body mass (kg) divided by height (m) squared (Table 1). The study has been approved by the Ethical Committee of the Medical University Graz.

Hyperbaric conditions

The simulated dives were performed in the dry, multiplace, hyperbaric chamber of the Department of Thoracic Surgery Graz. The pressure chamber was constructed by the Wagner Biro AG in 1968 and is the second greatest pressure chamber in the world.

TABLE 1
PERSONAL CHARACTERISTICS [MEAN VALUE±SD (MIN – MAX)] OF 68 MALE DIVERS

Age (yr.)	35.7±8.0 (15.1–55.4)
Height (cm)	179.3±5.2 (168–191)
Weight (kg)	83.8±13.5 (60.3–136.8)
BMI (kg/m)	26.0±3.8 (18.9–43.2)

9–10 subjects were exposed for about 40 min bottom time to a pressure of 6 bar (corresponding to a diving depth of 50 m) breathing compressed air. After that, decompression followed by breathing 100% oxygen. The decompression profiles of all 7 passages are presented in Table 2.

Measurement of subcutaneous adipose tissue topography (SAT-Top)

An optical device Lipometer has been developed at the Medical University Graz (EU patent Nr. 0516251), which enables a non-invasive, quick, precise and safe determination of the thickness of SAT-layers at any given site of the human body. The Lipometer gives detailed information of the distribution of the SAT-layer thicknesses. Therefore, the SAT-Top over the whole body, which is like an individual »fingerprint«, can be shown very exactly[22]. The sensor head of the Lipometer contains a set of light-emitting diodes (l = 660 nm) and a photodetector. For measuring the thickness of a SAT-layer, the sensor head is held perpendicular for 1–2 seconds to the specified body site. The SAT-layer is illuminated by different light patterns varying in time. A photodiode detects the corresponding back-scattered light intenities of the light patterns and calculates the thickness of the SAT-layer in millimeters[16]. The thickness of SAT-layers (in mm) of participants were measured at the left and the right side of the body both before and after exposure to the hyperbaric environment (Table 3).

TABLE 2
DECOMPRESSION PROFILES OF THE 7 HYPERBARIC PASSAGES

Depth 50m								
Bottom time (min.)	Decompression Stopps (meters)							Whole diving time (min.)
	20m	18m	15m	12m	9m	6m	3m	
55	3	2	3	3.5	9	22	61	178
46		5	3	4	5	16	43	141
40		4	3	3	4	13	35	123
35		3	2	3	4	10	30	110
45		5	5	5	5	18	60	160
36		4	4	4	5	20	45	140
35		3	3	4	6	12	35	118
40		4	3	4	6	20	43	140

TABLE 3

PERSONAL CHARACTERISTICS AND SAT-TOP MEASUREMENTS [MEAN VALUE±SD (MIN – MAX)] OF 68 MALE DIVERS BEFORE AND AFTER HYPERBARIC EXPOSITION TO 6 BAR

	Before hyperbaric treatment	After hyperbaric treatment	Significance of differences[1]
Waist (cm)	90.9±11.3 (72–135)	92.3±11.5 (73–132)	p=0.002
Hip (cm)	101.0±8.3 (84–139)	100.3±9.0 (76–142)	p=0.046
Whr	0.90±0.1 (0.8–1.1)	0.92±0.1 (0.7–1.1)	p=0.003
SAT-layer thicknesses of the right body side (mm):			
1-neck	7.0±3.7 (1.6–21.4)	7.4±3.9 (1.6–17.5)	p=0.035
2-triceps	5.5±2.6 (1.7–10.7)	5.6±2.4 (1.3–12.6)	n.s.[2]
3-biceps	3.8±2.8 (1.1–20.3)	4.5±3.2 (0.7–19.8)	p=0.001
4-upper back	5.3±2.1 (1.2–10.6)	5.5±2.2 (1.5–10.2)	n.s.
5-front chest	9.7±4.9 (1.2–23.1)	11.2±6 (2–31.3)	p<0.001
6-lateral chest	7.7±3.4 (1.6–15)	8.2±3.9 (1.6–21.5)	n.s.
7-upper abdomen	10.2±4.1 (1.3–20.4)	12.7±6 (1.8–34.2)	p<0.001
8-lower abdomen	9.0±3.9 (1.5–18.6)	10.9±5.4 (2–31.9)	p<0.001
9-lower back	7.0±2.5 (2.3–12.7)	7.0±2.8 (2.1–13.3)	n.s.
10-hip	9.8±3.7 (2.1–17.3)	10.0±4.1 (1.9–22)	n.s.
11-front thigh	4.1±1.8 (1.2–9)	4.3±2.1 (0.9–9.4)	n.s.
12-lateral thigh	3.4±1.8 (1.1–8.8)	3.1±1.6 (0.8–8.4)	n.s.
13-rear thigh	2.7±1 (1–5.3)	2.9±1.3 (1.2–7)	n.s.
14-inner thigh	5.4±2.5 (1.2–12.3)	5.5±2.4 (1.8–12.3)	n.s.
15-calf	2.2±0.9 (1–5.1)	2.3±0.9 (1.1–4.9)	n.s.
Upper trunk	29.7±12.3 (5.7–55.5)	32.3±13.9 (7.1–69.2)	p<0.001
Arms	9.32±4.7 (3.0–28.5)	10.1±4.9 (2.0–29.1)	p=0.017
Lower trunk	36.1±12.2 (8.4–57.1)	40.7±15.4 (8.1–76.7)	p<0.001
Legs	17.8±5.7 (7.6–32.1)	18.0±6.4 (6.7–38.0)	n.s.
Right SAT	92.8±20.7 (25.9–148.0)	101±34.2 (28–185.2)	p<0.001
SAT-layer thicknesses of the left body side (mm):			
1-neck	6.9±3.4 (1–14.7)	7.9±4.1 (1–19.9)	p=0.002
2-triceps	5.9±2.4 (1.7–11.6)	6.2±2.5 (1.7–11.6)	p=0.035
3-biceps	3.9±2.2 (1–11.5)	4.6±2.9 (1.2–14.4)	p=0.014
4-upper back	5.3±2 (1.5–9.4)	5.6±2.1 (1.4–11.8)	p=0.049
5-front chest	9.7±4.8 (1.3–20.9)	11.5±5.9 (1.5–27.6)	p<0.001
6-lateral chest	8.0±3.5 (1.4–17.3)	8.0±3.4 (1.4–17.6)	n.s.
7-upper abdomen	10.9±4.6 (1.2–21.6)	12.7±6.1 (1.4–34.8)	p<0.001
8-lower abdomen	9.2±3.6 (1.5–16.2)	10.8±5 (1.3–24.6)	p<0.001
9-lower back	7.2±3.2 (1.6–21.2)	6.6±3.1 (1.3–16.4)	p=0.039
10-hip	9.9±3.2 (1.9–16.1)	10.0±4.1 (1.8–23.5)	n.s.
11-front thigh	4.3±1.6 (1.3–8.4)	4.5±2 (1–9.9)	n.s.
12-lateral thigh	3.2±1.6 (1.1–7.8)	3.4±1.8 (1–9.6)	n.s.
13-rear thigh	2.9±1.2 (1–6.6)	3.3±2.1 (0.9–16.2)	n.s.
14-inner thigh	4.9±1.7 (1.2–9.3)	5.1±2.2 (1.1–10.5)	n.s.
15-calf	2.4±1.1 (0.7–6)	2.3±1 (0.8–5.5)	n.s.
Upper trunk	30.0±12.1 (6.6–50.9)	33.0±13.8 (6.0–60.6)	p<0.001
Arms	9.8±4.2 (2.9–19.7)	10.9±4.5 (3.1–21.0)	p=0.002
Lower trunk	37.3±12.4 (8.8–61.5)	40.2±15.4 (6.8–88.4)	p=0.003
Legs	17.7±5.4 (6.5–30.8)	18.7±7.1 (6.0–38.1)	n.s.
Left SAT	94.8±28.6 (26.9–148)	102.7±34.5 (24.2–13 7)	p<0.001
SAT layer thicknesses of both body sides (mm):			
Total SAT	187.6±57.9 (54.9–288)	203.8±68.1 (52.5–351)	p<0.001

[1] by nonparametric Wilcoxon test for dependent samples

[2] not significant (p>0.05)

Statistics

Statistical analysis were carried out using SPSS for Windows (version 16.0, 2008, SPSS Inc., Chicago, IL). The nonparametric Wilcoxon test for dependent samples was used to test the significance of SAT-Top differences before and after hyperbaric exposition.

A relative SAT-Top plot was constructed to visualise the SAT-layer variation. The mean values of the 15 SAT-layer thicknesses before hyperbaric exposure were set to 100%. The bars demonstrate the percental deviation of the SAT-layer thicknesses after hyperbaric exposition.

Results

The mean values of SAT-layer thicknesses are presented in Table 3. Comparing the two measurements, both, the left and the right SAT-layers of the upper body were significantly thicker after hyperbaric exposition at 1-neck, 3-biceps, 5-front chest, 7-upper abdomen and 8-lower abdomen. Furthermore, the left body side showed an additional significant increase at 2-triceps and 4-upper back, and a significant decrease at 9-lower-back.

Comparing the sums of SAT-layer thicknesses of upper trunk (1-neck, 4-upper-back, 5-front-chest, 6-lateral chest), arms (2-triceps, 3-biceps), lower trunk (7-upper abdomen, 8-lower abdomen, 9-lower back, 10-hip) and legs (11-front thigh, 12-lateral thigh, 13 rear-thigh, 14--inner thigh, 15-calf) before and after hyperbaric exposition, the sums of upper trunk, arms and lower trunk showed significant increases, whereas the sum of the legs did not change significantly.

The relative SAT-Top plot shows the relative increase (respectively decrease) of SAT-layer thicknesses after hyperbaric exposure (Figure 1). The mean values of the SAT-layer thicknesses before hyperbaric treatment were set to 100%. The right SAT-layers increased at 7-upper abdomen to 124.5%, at 8-lower abdomen to 121%, at 3-biceps to 118%, at 5-front chest to 115.5%, and at 1-neck to 107%. The left SAT-layers increased at 5-front chest to 119%, at 8-lower abdomen to 117.4%, at 7-upper abdomen to 116.5%, at 3-biceps to 115% and at 1-neck to 114%.

Discussion

Body fat distribution is sex specific and results in the typical male android (»apple like«) and female gynoid (»pear-like«) pattern of the older adolescent and the adult[23–25]. After decompression and leaving the pressure chamber, the probands showed significant increases of SAT-layer thicknesses at the upper body, especially at the zones upper abdomen, lower abdomen and front chest, but no significant increase of fatty tissue layers were found on the legs. For visualisation a SAT-Top plot was constructed, showing the development of the 15 specified SAT-layers at both body sides. The highest relative increase occurs at the upper abdomen (+24.5%) followed by the lower abdomen (+21%) at the right body side, and front chest (+19%) at the left body side.

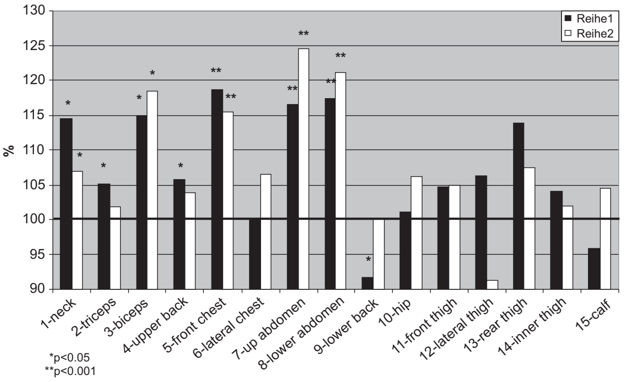

Fig. 1. Relative SAT-Top plot: Shows the relative increase (respectively decrease) of the SAT-layer thicknesses after hyperbaric exposure of the test persons for the 15 specified body sites. The 100% level stands for the average SAT-layer thicknesses before hyperbaric exposure. Results are shown seperatly with black bars for the left body side and white bars for the right side.

We suggest that the increase in the thickness of the SAT-layers is caused by the elevated N_2-accumulation of tissues at higher ambient pressures. According to Henry´s law the quantity of a dissolved gas is proportional to its partial pressure at the liquid surface. In a diving depth of 50 m the partial pressures of the breathing gases are elevated up to sixfold. Due to the different pressure gradients, the inert N_2 diffuses from blood into the tissues. The saturation of a tissue with an inert gas depends on temperature, diving depth, circulation and partial pressure of the gas[5]. Diffusion- and solubility tables for N_2 and for other gases in different mediums are described[8]. N_2 can diffuse into the fat cells and interstitials of the SAT-layers. Molecular solved N_2 forms gas bubbles, caused by the tendency to minimize the surface energy. The gas bubbles in the interstitials push the fat cells asunder. This deformation, together with the increase of the fat cell size, caused by N_2, might lead to the volume increase of the SAT-layer thicknesses, which is directly detectable with the Lipometer. N_2 is associated with decompression illness. The frequency of the incidence correlates with body weight and aerobic fitness. Higher aerobic fitness is a factor in protection from decompression sickness for men and women, because a lower degree of body fatness implies a lower N_2 content in body tissues[7]. N_2 can be accumulated at body sites where more body fat is stored. As men have thicker fat layers at the trunk and abdomen, N_2 diffuses into the SAT-layers of the upper body, however, none of the measured sites at the legs showed a change of SAT-layer thickness. This was also confirmed by comparing the sums of SAT-layer thicknesses of upper trunk (1-neck, 4-upper-back, 5-front-chest), arms (2-triceps, 3-biceps), lower trunk (7-upper abdomen, 8-lower abdomen, lower back, 10-hip) and legs (11-front thigh, 12-lateral thigh, 13 rear-thigh, 14-inner thigh, 15-calf) before and after hyperbaric exposition. The sums of the upper trunk, arms and lower trunk showed significant increases, whereas the sum of the body sites on the legs did not change significantly. As the human body fat distribution is not symmetric, a different blow up of SAT-layer thicknesses between the left and the right body side was observed.

In former studies changes of body fat distribution have been described in association with the metabolic syndrom, favoring a more gynoid one in men and a more android in women[26–29]. The »blow up« of the SAT-layers of the upper body proved that our probands generally had a typical male like, android body fat distribution. A pilote test was performed with 10 voluntary women under the same conditions and the increase of SAT-layers was measured at the femoral and gluteal zones (unpublished results).

To summarize we describe for the first time in detail the influence of a hyperbaric environment on quantitative and topographic changes of SAT.

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UTJECAJ VISOKOTLAČNOG OKRUŽENJA NA TOPOGRAFIJU POTKOŽNOG MASNOG TKIVA

SAŽETAK

Fiziološke tjelesne reakcije kod ronjenja moguće je stimulirati u visokotlačnoj komori, povećavanjem tlaka u prostoru. U ovoj se studiji istraživao utjecaj visokotlačnog okruženja od 6 bara na promjene debljine potkožnog masnog tkiva na različitim mjestima na tijelu, kod 68 dobrovoljaca s iskustvom ronjenja. Mjere topografije potkožnog masnog tkiva su dobivene optičkim uređajem Lipometer, prije i poslije izlaganja visokom tlaku. Uočen je značajan porast slojeva potkožnog masnog tkiva u gornjem dijelu tijela, gornjem abdomenu (+24,5%), donjem abdomenu (+21%) i prsima (+19%) nakon izlaganja visokom tlaku. Navedeni porast volumena se može objasniti nakupljanjem dušika u masnim stanicama kod povećanog pritiska. Dakle, u ovoj studiji se po prvi puta detaljno opisuje utjecaj visokotlačnog okruženja na kvantitativne i topografske promjene potkožnog masnog tkiva.