Biomedical Research 2017; Special Issue: S563-S567 *ISSN 0970-938X*
www.biomedres.info

The effect of wear of functional clothing included germanium fabrics on the anaerobic exercise capacity and fatigue, oxygen carrying capacity.

Kim Ji-yeon[1#], Park Dong-ho[2#], Kim Hyo-jin[1], Kim Gi-won[1], Shin Yun-a[3], Kim Chang-sun[1*]

[1]Department of Physical Education, Dongduk Women's University, Seoul, Republic of Korea

[2]Department of Kinesiology, Inha University, Incheon, Republic of Korea

[3]Department of Exercise Prescription and Rehabilitation, Dankook University, Cheonan, Republic of Korea

[#]These authors contributed equally to this work

Abstract

Purpose: This study examined the effects of wear of functional clothing included germanium fabrics for single short time on the anaerobic exercise capacity and fatigue, oxygen carrier capacity.
Methods: Ten middle-age female subjects (52.7 ± 3.3 years) were randomly assigned double blind test to wear of germanium-treated functional clothing (Ge) or control clothing (CON) by cross-over repeated design with biweekly. Functional fiber was treated with ion such as germanium, magnesium or silicon (patent application: 2016-0063434). Subjects were performed Wingate test to measure total work and fatigue index, and blood was collected before and after the test. Two-way (2 by 2 or 6) repeated measured ANOVA was used to find out the interaction between the group and time, and the criterion for significance was set at an alpha level of 5%.
Results: There were no significant differences between the two treatment groups in fatigue index, total work and peak power ($p>0.05$), and no differences were observed in blood lactate, glucose and oxygen saturation (SpO_2), blood pressure ($p>0.05$). No significant differences were also observed between the two treatment groups in serum fatigue variables such blood ammonia, dopamine, LDH, CK and cortisol ($p>0.05$). However, RBC, hemoglobin and red cell distribution width (RDW) of Ge group significantly increased after test ($p<0.05$, $p<0.01$ respectively) in spite of there were no changes in CON group.
Conclusion: These results suggest that wear of germanium functional clothing might to affect the improved oxygen carrying capacity.

Keywords: Germanium, Functional clothing, RBC, Hemoglobin, Anaerobic exercise capacity, Fatigue.

Accepted on April 24, 2017

Introduction

Advances in new materials by combining fiber chemistry and nanotechnology have led to the development of high-tech fibers that can effectively block electromagnetic waves and ultraviolet radiation, are capable of generating heat, are antibacterial, and which can emit radiation in the far infrared range. These developments in the textile industry have allowed the evolution of materials aimed at enhancing athletic performance. The scope of research into such "sports clothing" is, however, limited to items such as cooling materials that quickly release sweat during exercise, compression materials, or materials that minimize air and water resistance [1]. With a goal of adding value, materials capable of emitting far-infrared radiation have recently been attracting growing interest [2]. Wavelengths of 5 μm to 20 μm are beneficial to the human body, in that the far-infrared radiation penetrates the body, creating a warming effect through powerful resonance. This facilitates the metabolism and thus is recognized as being generally beneficial [3]. Ceramics [4] and germanium (Ge) both emit far-infrared rays. Given that Ge emits high levels of far-infrared radiation, compounds containing Ge have recently been incorporated into functional fabrics [5]. Some studies have revealed that Ge increases immunity [6], has an anti-inflammatory effect [7], promotes plant growth [8], and can remove heavy-metal contaminants [9]. However, very little research has been conducted on the enhancement of physical functions or athletic performance. Therefore, this study set out to investigate the effects of wearing a Ge-ion-treated clothing on anaerobic exercise ability, fatigue, and oxygen-carrying ability during anaerobic high-intensity exercise.

Materials and Methods

Ten middle-aged females (Age: 52.7 ± 3.3 years, Weight: 59.2 ± 5.0 kg, Height: 155.1 ± 3.6 cm, BMI: 24.6 ± 2.3 kg/m^2) were randomly selected. A double-blind test with a cross-over repeated design was performed twice with a one-week washout

period. The experiment was approved in advance by the Institutional Review Board (IRB) of Inha University (IRB approval no. 160825-2A).

Table 1. *The comparison of fatigue index and anaerobic physical fitness between two groups after Wingate test.*

Variable	Group		t	p
	CON	Ge		
Fatigue index (%)	25.10 ± 3.10	26.54 ± 2.14	-0.632	0.543
Total work (kpm)	668.96 ± 26.96	663.97 ± 27.42	0.328	0.750
Peak power (watt)	262.12 ± 13.13	262.14 ± 10.22	-0.003	0.998
Mean power (watt)	221.52 ± 8.48	219.36 ± 7.31	0.407	0.694

Mean±SE, CON, Control group; Ge, Germanium group.

Upon arriving at the lab after at least 12 h of fasting, the subjects were randomly divided into two groups: a control group (CON group) and a Ge group (GE group), each of which was asked to change into either a control clothing or Ge clothing, respectively. After resting for at least 30 min, they were asked to undertake a Wingate test to measure their anaerobic capacity and level of fatigue. One week later, the test was repeated, but the subjects were asked to wear a different clothing to the one they had worn for the first test. This study used functional fibers treated with ions such as germanium, magnesium, and silicon (Patent Application 2016-0063434). Several functions of the fibers, such as the emission of far-infrared radiation, harmless to the human body (Korea Far Infrared Association, KFI-653), as well as the antibacterial and deodorant functions (FITI Testing & Research Institute, 231-15-47171) were evaluated by professional institutions. Using the proposed fibers, six types of clothing including briefs, undershirts, leggings, short-sleeve shirts, shorts, and socks were fabricated as the functional clothings for the GE group, while identical clothings made with an untreated version of the same fabric was used for the CON group. The clothings were all of the same color so that neither the subjects nor the observers could distinguish between them. The Wingate test was performed using a dedicated measuring device (Excalibur Sport, Sweden) with maximum exercise duration of 30 s. The load on the pedal was set to about 0.05% of the subject's body weight. The fatigue index, total work, peak power, and mean power were calculated from the obtained results. Both before and after the Wingate test, 10 ml of blood were collected from the brachial vein. Furthermore, a fingertip test was performed before, immediately after, and in the recovery phase, 5, 10, 15, and 30 min after the end of the Wingate test.

Table 2. *The comparison of blood variables between two groups during and after Wingate test.*

Variable	Group	Before	Post test	5 min	10 min	15 min	30 min	Source	F(p)
Lactate (umol/l)	CON	0.98 ± 0.13	4.47 ± 0.22a	5.06 ± 0.26a	4.85 ± 0.38a	4.02 ± 0.31a	2.85 ± 0.16a	group	3.691 (0.087)
	Ge	0.82 ± 0.16	5.32 ± 0.40a	5.52 ± 0.25a	5.28 ± 0.27a	4.14 ± 0.24a	2.86 ± 0.24a	time	73.34 (0)
								g × t	3.707 (0.088)
Glucose (mg/dl)	CON	100.5 ± 4.2	107.6 ± 4.9	106.5 ± 4.7	102.6 ± 3.3	106.5 ± 6.1	98.1 ± 4.9	group	0.044 (0.840)
	Ge	107.4 ± 4.5	110.0 ± 4.6	107.4 ± 5.0	111.8 ± 5.8	104.3 ± 5.8	102.5 ± 4.3	time	2.865 (0.165)
								g × t	2.849 (0.166)
SpO_2 (%)	CON	97.2 ± 0.3	98.0 ± 0.2	97.8 ± 0.3	97.5 ± 0.3	97.1 ± 0.4	95.7 ± 0.5	group	2.450 (0.152)
	Ge	97.2 ± 0.4	97.9 ± 0.3	97.4 ± 0.3	96.9 ± 0.4	96.7 ± 0.3	96.6 ± 0.5	time	2.186 (0.205)
								g × t	0.815 (0.586)
SBP (mmHg)	CON	122.2 ± 3.7	130.5 ± 7.5	114.7 ± 3.9	117.7 ± 3.5	115.2 ± 4.0	118.1 ± 4.0	group	2.495 (0.149)
	Ge	126.0 ± 4.8	127.4 ± 4.3	117.8 ± 3.0	116.5 ± 3.0	120.6 ± 4.6	120.0 ± 2.4	time	0.940 (0.526)
								g × t	1.043 (0.482)
DBP (mmHg)	CON	80.6 ± 3.3	76.8 ± 2.5	70.3 ± 2.0	73.6 ± 2.1	73.9 ± 2.0	73.7 ± 2.3	group	2.835 (0.127)
	Ge	79.1 ± 3.1	76.1 ± 2.7	72.7 ± 1.5	73.5 ± 1.2	76.3 ± 2.4	76.3 ± 2.8	time	1.585 (0.313)
								g × t	2.986 (0.128)

Mean ± SE; CON: Control Group; Ge: Germanium Group. SpO2, Peripheral oxygen saturation; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure. a: p<0.001 *vs.* before by paired t-test.

Changes in the SpO_2, systolic blood pressure (SBP), and diastolic blood pressure (DBP) levels (Tango M2, Suntech medical, USA), as well as the lactate (YSI1500, Instruments, USA) and glucose levels (Accu-check, Loche, Italy) were observed. Venous blood tests, to determine the pre- and post-test values for the lactate, glucose, ammonia, dopamine, lactate dehydrognase, creatine kinase, cortisol, RBC and hemoglobin, hematocrit, and red cell distribution width (RDW) were undertaken by a commercial laboratory (SQLab, Seoul). A statistical analysis was performed using SPSS 22.0. Two-way repeated-measure ANOVA was conducted to analyze the differences in the time period (2 or 6 periods) for each group (CON group and GE Group). One-way ANOVA and paired t-

tests were used as post hoc tests for each time period. The significance level was set to $p<0.05$.

Results

The effects of wearing Ge-treated functional clothings on anaerobic exercise capacity were verified through observation of the fatigue index, total work, peak power, and mean power (Table 1). However, across all of these observations, no statistically significant differences were observed between the two groups. Moreover, no significant differences were observed in the times for the two groups or between the glucose, SpO_2, SBP, or DBP levels during the recovery period after the end of the Wingate test (Table 2). The lactate levels increased by more than five times immediately after the test but fell to their original levels after 30 min of recovery ($p<0.001$), with there being no significant difference between the two groups (NS). In the same way as with the fingertip test results, the level of blood lactate in the venous blood increased by more than 5 to 6 times ($p<0.001$) for both groups, but there was no significant difference between them (Table 3). For the ammonia, there was an interaction between the group and time period ($p=0.014$), but post hoc tests showed an increase in the ammonia levels after the test for both groups ($p<0.001$). The rate of change in the oxygen-carrying capacity of the blood is shown in Figure 1. The number of RBCs was statistically significant ($p=0.048$), remaining unchanged in the CON group but increasing in the GE group ($p<0.05$). Similarly, the amount of hemoglobin remained unchanged for the CON group but exhibited a statistically significant increase for the GE group ($p<0.05$). Furthermore, a statistically significant increase in the RDW level after the end of the Wingate test was found only for the GE group ($p<0.05$).

Table 3. *The comparison of serum fatigue variables between two groups after Wingate test.*

Variable	Group	Before	After	Source	F(p)
Lactate (umol/l)	CON	0.90 ± 0.08	5.67 ± 0.38***	group	0.003 (0.954)
	Ge	0.76 ± 0.06	5.84 ± 0.66***	time	120.567 (0)
				g × t	0.306 (0.594)
Glucose (mg/dl)	CON	89.0 ± 2.50	93.7 ± 3.63	group	0.033 (0.859)
	Ge	90.6 ± 1.33	93.0 ± 3.50	time	2.553 (0.145)
				g × t	0.199 (0.666)
Ammonia (umol/l)	CON	103.4 ± 4.70	126.5 ± 6.55***	group	0.214 (0.654)
	Ge	94.8 ± 4.77	128.8 ± 4.57***	time	62.742 (0)
				g × t	9.275 (0.014)
Dopamin (pg/ml)	CON	24.4 ± 2.36	20.3 ± 3.02	group	4.006 (0.076)
	Ge	27.7 ± 5.54	32.7 ± 5.11	time	0.024 (0.880)
				g × t	0.944 (357)
LDH (U/L)	CON	207.2 ± 8.64	231.0 ± 12.10	group	7.251 (0.025)
	Ge	187.4 ± 4.70	202.1 ± 10.58	time	6.763 (0.029)
				g × t	0.147 (0.710)
CK (U/L)	CON	110.7 ± 8.27	112.5 ± 7.8	group	0.012 (0.915)
	Ge	109.1 ± 12.83	112.2 ± 12.94	time	4.628 (0.060)
				g × t	0.472 (0.509)
Cortisol (ug/dl)	CON	14.36 ± 1.36	15.88 ± 1.49	group	1.300 (0.284)
	Ge	15.90 ± 1.19	17.28 ± 1.64	time	1.620 (0.235)
				g × t	0.007 (0.934)

Mean ± SE, CON, Control group; Ge: Germanium Group; LDH: Lactate Dehydrognase; CK: Creatine Phosphokinase. *p<0.05, **p<0.01, ***p<001 *vs.* before by paired t-test.

Discussion

The results of the Wingate test performed as part of this study imply that the one-time wearing of a Ge-treated functional clothing does not affect anaerobic exercise capacity. This study also revealed that a one-time wearing does not inhibit the production of Wingate test-induced byproducts such as the stress hormone, cortisol [10], and the peripheral fatigue substances, lactate and ammonia [11], or the central fatigue substance, dopamine [12]. Moreover, it was also found to have no impact on the recovery of the lactate and glucose levels after exercise.

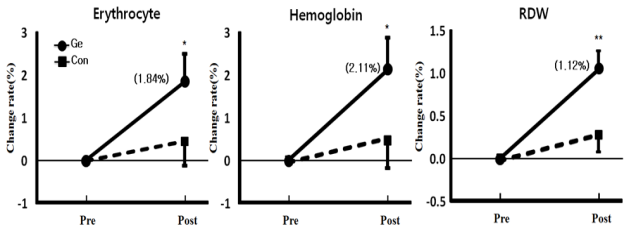

Figure 1. *The comparison of change rate (%) of oxygen carrying capacity between two groups after Wingate test; Ge: Germanium Group; CON: Control Group; *: p<.05, **:p<0.01 vs. Pre.*

In contrast, the amounts of hemoglobin and RBC, which serve to carry oxygen in the blood, were found to be significantly increased in the GE group after the Wingate test. The RDW value, which is used as an indicator of iron deficiency anemia [13], and which simultaneously represents the individual RBC volume differences, was also found to increase. This is the most important finding in this study as it points to the fact that wearing a Ge-treated functional clothing enhances the oxygen-carrying capacity of the blood during short-term, high-intensity exercise.

RBC acts as a carrier of oxygen throughout the body. The main component of RBC is hemoglobin, a protein-iron compound that binds and transports oxygen and carbon dioxide. RBCs are mainly differentiated from stem cells in the bone marrow, producing approximately 2.4 million erythrocytes every second [14]. It takes about seven days for RBC to mature and its lifespan is known to be about 100 to 120 days [15]. The human body rapidly produces RBC as a defense mechanism when exposed to anoxic and hypoxic conditions [16]. Training in a hypoxic environment has been reported to increase the body's RBC and hemoglobin levels within 24 h [17]. On the other hand, it is very unusual for the RBC count and hemoglobin concentration to increase in a short time, although this was observed to occur in the present study. This RBC and hemoglobin increase, however, may occur for a few minutes as a result of the actions of the body's defense mechanisms after exposure to high-intensity anaerobic conditions. We would expect the wearing of a Ge-treated functional clothing to accelerate the RBC production. In fact, it has been reported that organic Ge enhances the intracellular oxygen supply [18], while the consumption of Ge in animals increases blood RBC levels [19].

Meanwhile, it has been reported that RBC, when subjected to shear stresses caused by vasoconstriction, produces ATP to enhance the blood flow [20] and controls the vascular tone using nitric oxide (NO) derived from L-arginine [21]. In addition, RBC has been shown to dilate blood vessels by releasing S-nitrosothiol if oxygen is removed from the hemoglobin [22]. Therefore, more detailed studies will be needed to further investigate other variables related to RBC production and function, such as erythropoietin (EPO) and nitric oxide (NO), along with additional studies of the effects of a Ge functional clothing on blood flow change and vasodilation.

We can conclude that the one-time wearing of Ge-treated functional clothing does not affect variables such as anaerobic exercise capacity, the production of fatigue substances, and stress. It may, however, influence the oxygen-carrying capacity of hemoglobin and RDW as well as the amount of RBC.

Acknowledgement

This work was supported by the (2016 Scientific Research Fund of Dream Weavers Inc.) under Grant (NO. Dongduk-2016-00052) and World Class Smart Laboratory (WCSL) at Inha University.

References

1. Youn SW, Kim KJ, Kim YS, Shin JT. The Effect of Functional Sportswear Treated by Platium Nano on Energy Expenditure and Subjective Wearing Sensation. Korean J Sport Sci 2009; 20: 791-801.
2. Lee MC, Lee DT, Lee WY, Kim KY. Influence of A.I.S. Nano Infrared Emission Functional Clothing and Exercise on Body Composition, Skin Elasticity, Energy Expenditure and Perceptual Satisfaction. J Kor Soc Living Environ Sys 2011; 18: 545-553.
3. Lee JM, Kang BC, Yeom TY, Choi JJ, Bin SI. Well-being Industry and Ceramic. Ceramic Korea 2009; 22: 77-79.
4. Kim SK. The Effects of Functional compression garment wearing of Far-infrared Emission on Body Composition in middle-aged woman. Korean J Sports Sci 2010; 19: 1263-1275.
5. Kim HA, Kim SJ. Far-Infrared Emission Characteristics of Germanium Included Fabrics for Emotional Garment. Sci Emotion Stability 2010; 13: 687-692.
6. Suzuki F, Brutkiewicz RR, Pollard RB. Cooperation of lymphokine(s) and marco-phage in expression of antitumor activity of carboxyethylgermanium (Ge-132). Antitumor Res 1986; 62: 177-182.
7. Sasaki K, Ishikawa M, Monma K, Takayanagi G. Effect of carboxyethyl germanium sesquioxide (Ge-132) on the acute inflammation and CCl4-induced hepatic damage in mice. Pharmacometrics 1984; 27: 1119-1131.
8. Han MJ, Kim SU, Seo DC, Cheong YH, Lee DJ, Park MS, Rim YS, Sohn BK, Heo JS, Cho JS. Uptake Properties of Germanium to Vegetable Plants and Its Effect on Seed Germination and on Early Stage Growth. Korean J Environ Agriculture 2007; 26: 217-222.
9. Lee KH. A Study on Characteristics of Adsorption of Germanium for Heavy Metals. J Korean Soc Environ Anal Sci Emotion Sensibility 2005; 8: 213-218.
10. Moon HW, Kim JG. The Effects of Exercise and Electrical Stimulation on Maximal Exercise Capacity, Lipid Metabolism and Hormonal Changes. Korea Sport Res 2004; 15: 1989-2000
11. Simonson E. Physiology of work capacity and fatigue, Springfield. IL., Charles C. Thomas, 1971.
12. Lukaszyk A, Buckzo W, Wisniewski K. The efferct of strenuous exercise on the reactivity of the central dopaminergic system in the rat. Pol J Pharmacol Pharm 1983; 35: 29-36.
13. Bergin JJ. Evaluation of anemia. Postgrad Med 1985; 77: 253-269.
14. Erich S. Biological Membranes Architecture and Function, Handbook of Biological Physics, ed. R.Lipowsky and E.Sackmann, Elsevier, 1995.
15. Harrison KL. Fetal Erythrocyte Lifespan. Aust Paediatr J 1979; 15: 96-97.
16. Formenti F, Constantin-Teodosiu D, Emmanuel Y, Cheeseman J, Dorrington KL, Edwards LM, Humphreys SM, Lappin TRJ, McMullin MF, McNamara CJ, Mills W, Murphy J, O'Connor DF, Percy MJ, Ratcliffe PJ, Smith TG, Treacy M, Frayn KN, Greenhaff PL, Karpe F, Clarke K, Robbins, PA. Regulation of human metabolism by hypoxia-inducible factor. Proc Natl Acad Sci USA 2010; 107: 12722-12727.
17. Wehrlin JP, Zuest P, Hallen J, Marti B. Live high-train low for 24 days increases hemoglobin mass and red cell volume in elite endurance athletes. J Appl Physiol 2006; 100: 1938-1945.

18. Levine SA, Kidd PM. Oxigen-nutrition for super health. J. Orthomol Medicine 1986; 1: 145.
19. Goodman S. Therapeutic effects of organic germanium. Med Hypotheses 1988; 26: 207-215.
20. Wan J, Ristenpart WD, Stone HA. Dynamics of shear-induced ATP release from red blood cells. Proc Natl Acad Sci USA 2008; 105: 16432-16437.
21. Kleinbongard P, Schulz R, Rassaf T, Lauer T, Dejam A, Jax T, Kumara I, Gharini P, Kabanova S, Ozüyaman B, Schnürch HG, Gödecke A, Weber AA, Robenek M, Robenek H, Bloch W, Rösen P, Kelm M. Red blood cells express a functional endothelial nitric oxide synthase. Blood 2006; 107: 2943-2951.
22. Diesen DL, Hess DT, Stamler JS. Hypoxic vasodilation by red blood cells: evidence for an s-nitrosothiol-based signal, Circ Res 2008; 103: 545-553.

***Correspondence to**

Kim Chang-sun

Department of Physical Education

Dongduk Women's University

Republic of Korea