

## The Impact of Moderate Physical Exercise on the Rheological and Biochemical Properties of Blood in Osteoarthritis Patients Who Are Regular Winter Swimmers

Małgorzata STRZELCZYK, Aneta TELEGLÓW<sup>ID</sup>, Jakub MARCHEWKA<sup>ID</sup>, Bartłomiej PTASZEK<sup>ID</sup>,  
and Anna MARCHEWKA<sup>ID</sup>

Accepted March 23, 2021

Published online March 31, 2021

Issue online March 31, 2021

Original article

STRZELCZYK M., TELEGLÓW A., MARCHEWKA J., PTASZEK B., MARCHEWKA A. 2021. The impact of moderate physical exercise on the rheological and biochemical properties of blood in osteoarthritis patients who are regular winter swimmers. *Folia Biologica (Kraków)* 69: 31-37.

The aim of this study was to assess the influence of moderate physical exercise on selected blood parameters in regular winter swimmers who suffer from osteoarthritis. The study covered a period of 6 months, from November to April, and was carried out on 17 women and 22 men. The participants were divided into 4 groups: Female CWI – women who only immersed themselves in cold water, Female CWI + PE – women who exercised in addition to water immersion, Male CWI – men who only immersed themselves in cold water, and Male CWI + PE – men, who exercised in addition to water immersion. Venous blood was collected twice, before and after the exercise program. A statistically significant decrease in fibrinogen, plasma viscosity, T<sub>1/2</sub>, and AMP was observed in the blood of people who did not take part in the physical exercise program while a significant decrease in cortisol levels was observed in the people who participated in the exercise program in addition to cold water immersion. In terms of rheological parameters, a significant increase in the elongation index (EI) of erythrocytes from shear stress 2.19 Pa in all groups was observed. There were no statistically significant changes in AI in all groups. Physical activity has an influence on the blood parameters of elderly winter swimmers suffering from osteoarthritis.

Key words: Winter swimming, physical exercises, osteoarthritis, blood parameters, elongation index.

Małgorzata STRZELCZYK, Aneta TELEGLÓW<sup>✉</sup>, Jakub MARCHEWKA, Bartłomiej PTASZEK, Anna MARCHEWKA,  
University of Physical Education in Cracow, 78 Jana Pawła II Street, 31-571, Kraków, Poland.  
E-mail: Aneta.Teleglow@awf.krakow.pl

The rheological properties of blood change under the influence of physical effort. The changes depend on many factors, such as: duration, intensity, and type of exercise. An increase in plasma viscosity is the short-term effect of exercise. Medium-term effects of physical effort cause an increase in blood fluidity which results in a raised plasma volume and thus reduces plasma viscosity. Long-term effects improve blood fluidity with hormonal changes caused by working out (BRUN *et al.* 1998).

It has been observed that plasma and blood viscosity increases as humans get older. We could associate this process with a decrease in red blood cells' elasticity, an increase of the aggregation index, and a drop in blood vessel flow. These factors may induce increased risk of cardiovascular diseases in people at elderly age. Therefore, applied therapy should take

into consideration the enhancement of rheological blood properties (FEHER *et al.* 2006).

Applying different forms of cryotherapy and rehabilitation are popular therapeutic methods for elderly people with musculoskeletal diseases, among them we could distinguish people who suffer from osteoarthritis (KULIS *et al.* 2017).

Physical exercise is highly recommended as a first form of treatment for osteoarthritis. There are many benefits of physical activity, such as: an increase in muscle power, better repair of cartilage's articular surface, and decreasing the risk of cardiovascular disorders (GLOTH & MATESEI 2001; JONSDOTTIR *et al.* 1997; RODDY *et al.* 2005).

Our hypothesis assumes that moderate physical exercise has an influence on the rheological and bio-

chemical properties of blood in osteoarthritis patients who are regular winter swimmers.

The aim of this paper was to assess the impact of moderate physical activity on the biochemical and rheological parameters of blood in regular winter swimmers who suffer from osteoarthritis.

## Material and Methods

### Study group

The study was approved by the Ethical Committee at the Regional Medical Chamber in Krakow (approval No.: 17/KBL/OIL/2015).

The study involved 39 people (17 women and 22 men) between the age of 45 and 68 years old (mean age 54.24) from the Cracow Winter Club „Kaloryfer” (Fig. 1). All participants were diagnosed with osteoarthritis. The inclusion criteria for the study were as follows: being between 45 and 70 years old, a diagnosis of osteoarthritis (first stage in Seyfried’s scale) made by a physician specializing in orthopedics, being a winter swimmer for at least 2 seasons before the study, no contraindications to physical effort or winter swimming, and a voluntary agreement to take participation in the study. Exclusion criteria included: unregulated arterial hypertension, local disorders of blood circulation, atherosclerosis, urinary tract disorders (such as bladder infections), contraindications to physical effort or winter swimming, and participation in other forms of regular physical activity throughout the period of the study. All participants completed the full cycle of research.

The subjects were recruited voluntarily and had to comply with the inclusion and exclusion criteria.

The women and men were randomly divided into 4 groups. The first group consisted of 7 women who

only immersed themselves in cold water (Female CWI). The second group consisted of 10 women who immersed themselves in cold water after taking participation in a physical exercise program (Female CWI + PE). The third group consisted of 12 men who only immersed themselves in cold water (Male CWI). Lastly, the fourth group consisted of 10 men who immersed themselves in cold water after participating in a physical exercise program (Male CWI + PE) (Table 1). The different sizes of the groups was due to the fact that one person from the Male CWI + PE group quit the exercise program and moved to the Male CWI group (before the study started) while 3 participants from the original Female CWI group asked to change study groups because they wanted to take part in the exercise programs. There was no control group because we wanted to check the impact of moderate, physical exercise in regular winter swimmers who suffered from osteoarthritis. We decided to draw blood twice – before the exercises started (in November 2015) and after the physical exercise programs ended (in April 2016). We did not compare the changes with healthy people who did not exercise or winter swim. However, taking into consideration the fact that changes in blood properties may change a little bit seasonally, further study is required.

Table 1

Characteristics of participants

Sex	Factor	n
Female	CWI	7
Female	CWI + PE	10
Male	CWI	12
Male	CWI+PE	10

CWI – cold water immersion; PE – physical exercises.

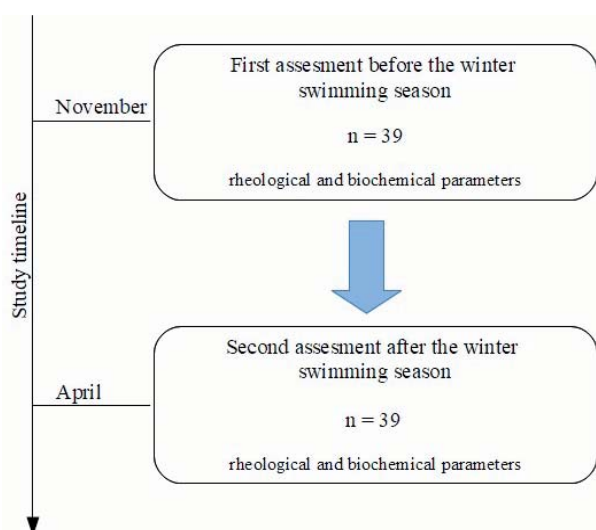


Fig. 1. Study design flowchart

Groups Female CWI and Male CWI immersed themselves in cold water once a week for 3-5 minutes. Groups Female CWI + PE and Male CWI + PE exercised once a week, for 45 minutes in their respective groups. The exercise started with a warm-up (10 minutes) and involved active exercises to strengthen the muscles of the back, abdomen, and limbs. Thera-band tapes were used. The intensiveness of the exercise was measured with Borg’s scale and did not exceeded 14 (BORG 1982). The program involved exercises of the upper limbs with Thera-band tapes and exercises of the lower limbs while standing, lying on one’s back, and on one’s stomach. There were also exercises that worked the abs and torso. Cold water immersion followed directly after the exercises. The length of the treatment was 6 months. The temperature of water was 0.2-7°C. The temperature was measured once a week at 8 a.m. and the average temperature during the winter season was estimated.

### Study protocol

Blood was collected twice – at the beginning of the exercise program in November 2015 and at the end in April 2016. The blood samples were collected in the morning, before cold water immersion on the first and last days of the exercise program. The samples were collected in vacuum tubes with K<sub>2</sub>EDTA. The level of cortisol, fibrinogen, plasma viscosity, and erythrocyte elongation and aggregation indices were checked. Blood was collected on an empty stomach.

The parameters of blood were analyzed in the Laboratory of Blood Physiology of the University of Physical Education in Cracow.

The concentration of cortisol was determined with a Roche Diagnostics e411 Cobas analyzer. The total time of measurement was 18 minutes. Results were deciphered using 2-point calibration. It was assessed by an appropriately sensitive enzyme-linked immunosorbent assay (ELISA).

The level of fibrinogen was determined using a Chrom 7 coagulometer produced by Bio-Ksel. The measurement was based on changes in optic density occurring during the clotting reaction and kinetic analysis of the process. The results were described in g/l.

To obtain information about the rheological properties of the blood samples, plasma viscosity, and elongation and aggregation indices were measured.

The viscosity of blood plasma was determined in a viscosimeter Roetgen type D-52159.

Aggregation and elongation indices were determined using a Laser-assisted Optical Rotational Cell Analyzer (LORCA) according to the Hardeman's method. The aggregation parameters were described by aggregation index (AI, in %), the amplitude and total extent of aggregation (AMP, in arbitrary units), and the half time (T<sub>1/2</sub>, in s). The elasticity of the erythrocytes was expressed using the elongation index (EI).

To obtain information about the aggregation of red blood cells, 1-2 ml of a blood sample was transferred into a glass vessel and was oxygenated with ambient air for 10 minutes. 1 ml of oxygenated blood would then be added to the cup of a LORCA analyzer. The cup was set into rotational movement within 120 seconds. The blood sample was sheared at 400 s<sup>-1</sup> and after 10 seconds, centrifugation was rapidly stopped and red blood cells would begin to aggregate. The aggregation index was calculated using a syllectogram. Afterwards, the aggregation index, T<sub>1/2</sub>, and AMP were calculated using a computer program.

To measure the deformability of erythrocytes 5 ml 14 mM polyvinylpyrrolidone (PVP) dissolved in PBS was added to 25 µl of blood (the vials were filled with EDTA anti-coagulant). The measurement was based on the graduated impact of centrifugal force on the erythrocytes suspended in the PVP mixture with a LORCA analyzer. The red blood cells' elasticity

was expressed through the elongation index with the different values of shear stress from 0.3-60.3 Pa using a graph illustrating the relationship between elongation index and applied pressure.

To acquire the plasma viscosity level a few procedures were done. The plasma incurred after the centrifugation of other blood components was exposed to freezing temperatures (-65°C) within 10 minutes. After defrosting, the plasma would then be placed in a capillary viscometer. The time it took the plasma to flow between light points was measured. The pressure and temperature inside the capillary was fixed. Afterwards, dynamic viscosity occurred and was calculated using Hagen Poiseuille's law.

### Statistical analysis

The study results were compiled with Statistica 10 (StatSoft®). The differences between the groups were checked using an ANOVA test with repeated measurements with additional factors: sex and physical exercise. When a factor was significant, further analysis was done using a post hoc HSD test. Variables that did not comply with assumptions (compliance with a normal distribution, homogeneity of variance in sub-groups, equality matrix covariance) were transformed using a Box-Cox transformation. The statistical significance was defined as p<0.05.

## Results

An analysis of the mean values of the biochemical and rheological parameters in the groups that only immersed themselves in cold water showed a significantly lower fibrinogen level (g/dl), plasma viscosity (mPa), total extent of aggregation – AMP (%), and half time of aggregation – T<sub>1/2</sub> (s) from the beginning versus the end of the study. These results can be seen in Table 2. However, there were no statistically significant changes in the aggregation index (AI) (%) and cortisol levels (nmol/l) of these groups (Table 2).

In groups that exercised in addition to cold water immersion, the level of cortisol had decreased from pre-study levels (Table 3). These groups did not show any statistically significant changes in plasma viscosity, fibrinogen, AI, T<sub>1/2</sub>, or AMP, however, when comparing their pre- and post-study results (Table 3).

The elasticity of erythrocytes from shear stress 2.19 Pa significantly increased in all groups (Tables 4, 5). It is worth noting that the participants' elongation index did not increase at lower values of shear stress. It is quite possible that it would be necessary to put a higher pressure on red blood cells to deform them. Elasticity increased gradually.

Table 2

Mean values ( $\pm$ SD) of hematological parameters before and after the winter swimming season in women and men who did not exercise

Parameter	Female CWI			Male CWI		
	Before	After	p	Before	After	p
Cortisol (nmol/l)	396.36 $\pm$ 134.29	442.67 $\pm$ 114.04	NS	412.57 $\pm$ 85.15	405.18 $\pm$ 140.34	NS
Plasma v. (mPa)	1.20 $\pm$ 0.06	1.01 $\pm$ 0.09	0.05	1.16 $\pm$ 0.16	1.08 $\pm$ 0.10	0.05
Fibrinogen (g/dl)	4.69 $\pm$ 0.79	3.76 $\pm$ 0.74	0.01	4.05 $\pm$ 0.87	3.89 $\pm$ 1.36	0.01
AI (%)	58.33 $\pm$ 2.35	59.37 $\pm$ 6.09	NS	57.79 $\pm$ 7.58	60.63 $\pm$ 6.65	NS
T $\frac{1}{2}$ (s)	2.83 $\pm$ 0.35	2.36 $\pm$ 0.53	0.05	2.99 $\pm$ 1.00	2.48 $\pm$ 0.84	0.05
AMP (%)	21.97 $\pm$ 2.92	15.36 $\pm$ 4.37	0.01	20.92 $\pm$ 2.54	16.74 $\pm$ 3.00	0.01

NS – non significant; Plasma v. – plasma viscosity

Table 3

Mean values ( $\pm$ SD) of hematological parameters before and after the winter swimming season in women and men who exercised

Parameter	Female CWI + PE			Male CWI + PE		
	Before	After	p	Before	After	p
Cortisol (nmol/l)	336.99 $\pm$ 140.55	311.87 $\pm$ 97.48	0.01	394.96 $\pm$ 93.47	374.16 $\pm$ 127.35	0.01
Plasma v. (mPa)	1.23 $\pm$ 0.11	1.10 $\pm$ 0.09	NS	1.15 $\pm$ 0.08	1.0 $\pm$ 0.10	NS
Fibrinogen (g/dl)	4.49 $\pm$ 1.21	4.29 $\pm$ 0.88	NS	4.70 $\pm$ 1.20	3.77 $\pm$ 0.91	NS
AI (%)	58.09 $\pm$ 9.77	60.86 $\pm$ 7.56	NS	56.63 $\pm$ 4.61	60.36 $\pm$ 7.37	NS
T $\frac{1}{2}$ (s)	2.71 $\pm$ 1.38	2.15 $\pm$ 0.61	NS	3.09 $\pm$ 0.67	2.69 $\pm$ 0.63	NS
AMP (%)	18.38 $\pm$ 5.18	15.77 $\pm$ 3.92	NS	18.45 $\pm$ 4.24	16.08 $\pm$ 3.48	NS

NS – non significant; Plasma v. – plasma viscosity

Table 4

Mean values ( $\pm$ SD) of the elongation index (EI) at various levels of shear stress in women and men who immersed in cold water and took participation in a rehabilitation program (before and after the winter season)

Shear stress (Pa)	Female CWI + PE			Male CWI + PE		
	Before	After	p	Before	After	p
0.30	0.193 $\pm$ 0.05	0.120 $\pm$ 0.09	NS	0.198 $\pm$ 0.04	0.104 $\pm$ 0.07	NS
0.58	0.246 $\pm$ 0.04	0.111 $\pm$ 0.07	NS	0.252 $\pm$ 0.04	0.118 $\pm$ 0.09	NS
1.13	0.117 $\pm$ 0.04	0.108 $\pm$ 0.03	NS	0.157 $\pm$ 0.05	0.129 $\pm$ 0.03	NS
2.19	0.095 $\pm$ 0.01	0.134 $\pm$ 0.07	0.05	0.166 $\pm$ 0.24	0.167 $\pm$ 0.06	0.05
4.24	0.168 $\pm$ 0.01	0.214 $\pm$ 0.09	0.05	0.156 $\pm$ 0.01	0.235 $\pm$ 0.09	0.05
8.24	0.255 $\pm$ 0.02	0.284 $\pm$ 0.10	0.05	0.244 $\pm$ 0.02	0.309 $\pm$ 0.09	0.05
15.98	0.332 $\pm$ 0.02	0.339 $\pm$ 0.11	0.05	0.316 $\pm$ 0.02	0.339 $\pm$ 0.11	0.05
31.03	0.379 $\pm$ 0.03	0.440 $\pm$ 0.06	0.01	0.367 $\pm$ 0.03	0.370 $\pm$ 0.10	0.01
60.30	0.442 $\pm$ 0.12	0.487 $\pm$ 0.09	0.05	0.431 $\pm$ 0.12	0.444 $\pm$ 0.06	0.05

NS – non significant

Table 5

Mean values ( $\pm$ SD) of the elongation index (EI) at various levels of shear stress in women and men who only immersed in cold water (before and after the winter season)

Shear stress (Pa)	Female CWI			Male CWI		
	Before	After	p	Before	After	p
0.30	0.232 $\pm$ 0.06	0.067 $\pm$ 0.04	NS	0.195 $\pm$ 0.22	0.091 $\pm$ 0.05	NS
0.58	0.253 $\pm$ 0.03	0.091 $\pm$ 0.16	NS	0.250 $\pm$ 0.27	0.140 $\pm$ 0.07	NS
1.13	0.155 $\pm$ 0.05	0.110 $\pm$ 0.01	NS	0.137 $\pm$ 0.03	0.127 $\pm$ 0.03	NS
2.19	0.093 $\pm$ 0.01	0.189 $\pm$ 0.23	0.01	0.087 $\pm$ 0.01	0.114 $\pm$ 0.05	0.01
4.24	0.160 $\pm$ 0.01	0.244 $\pm$ 0.07	0.01	0.156 $\pm$ 0.01	0.169 $\pm$ 0.07	0.01
8.24	0.245 $\pm$ 0.01	0.318 $\pm$ 0.07	0.05	0.238 $\pm$ 0.02	0.237 $\pm$ 0.08	0.05
15.98	0.325 $\pm$ 0.02	0.373 $\pm$ 0.07	0.05	0.312 $\pm$ 0.02	0.395 $\pm$ 0.08	0.05
31.03	0.379 $\pm$ 0.03	0.440 $\pm$ 0.06	0.01	0.367 $\pm$ 0.03	0.370 $\pm$ 0.03	0.01
60.30	0.442 $\pm$ 0.02	0.497 $\pm$ 0.07	0.05	0.431 $\pm$ 0.03	0.444 $\pm$ 0.46	0.05

NS – non significant.

## Discussion

The research presented in this paper is unique because among the studies published so far, there are no reports on the influence of physical exercise on the rheological and biochemical properties of blood in regular winter swimmers who suffer from osteoarthritis. We intended to show the influence of moderate physical exercise in patients who are regular winter swimmers, however, we noticed that the influence of winter swimming was so strong that the changes in blood properties in people who exercised additionally were not particularly higher as supposed before the research started. Some limitations could be caused by the mild intensity of the exercise program. The changes that appeared in the groups of winter swimmers who exercised demand further study and should be compared also with a control group to confirm that the recorded changes in blood were not seasonal and random.

Taking up various forms of physical activity has an influence on the rheological parameters of blood. This is important in elderly people whose blood properties are physiologically worse and it is more difficult to keep them at an appropriate level. In our study, changes in the deformability of erythrocytes under the influence of physical activity were observed in all groups. Statistically significant differences in mean elongation index values were observed at shear stress above 2.19 Pa, however, no statistically significant changes in EI below 2.19 Pa were observed in all groups. MARCHEWKA *et al.* observed a significantly higher level of elongation index with lower shear stress values (0.3 and 0.58 Pa) in people who underwent a rehabilitation program but no significant changes in the elongation index were observed at higher shear stress values.

TELEGLÓW *et al.* noticed an increase in the elongation index at shear stress from 1.13 Pa after a summer break in the winter baths of winter swimmers. But during this pause, the subjects took up various forms of physical activity such as canoeing, hiking, swimming, or running. These reports suggest an increase in the elasticity of erythrocytes during the break between seasons and, according to the authors, this phenomenon is difficult to explain. Presumably, this is because the tested people were well trained and taking up various forms of physical activity (cycling, running, swimming) and this had a real impact on improving the elasticity of erythrocytes during their break from winter baths. However, no significant changes were observed in the mean values of the aggregation index and fibrinogen concentration (TELEGLÓW *et al.* 2015).

In light of the quoted studies, we can conclude that physical activity of regular winter swimmers has a significant impact on the rheological properties of blood. In most studies we can observe an increase in the elongation index at some shear stress values which increases the deformability of red blood cells. This is a beneficial phenomenon and results in blood cells being able to reach capillaries with an exceedingly small diameter and it has a direct impact on the transport of respiratory gases and providing oxygen to cells.

CHRISTY *et al.* 2010 and WOODWARD *et al.* 1999 confirm the phenomenon of the deterioration of the rheological properties of blood at an elderly age. The authors observed a decrease in the elasticity of erythrocytes which leads to a decrease in blood flow and an increase in plasma viscosity. Under these conditions, the aggregation of red blood cells increases which is unfavorable in the elderly (CHRISTY *et al.* 2010) (WOODWARD *et al.* 1999). Increased aggregation of erythrocytes with a simultaneous increase in the viscosity of plasma is an unfavorable phenomenon that

may impair blood flow and, in some situations, may even lead to cardiac arrest (TURCZYŃSKI *et al.* 2004).

In our studies, no changes characteristic of elderly people were observed, even though our participants belonged to the group of middle-aged and elderly people. This is related to the regular winter swimming of the subjects, as well as being physically active between winter seasons. It is particularly important to notice that in our own research, the concentration of fibrinogen and plasma viscosity decreased under the influence of regular winter swimming (CWI groups) and that there were no significant changes in the red blood cell aggregation index which is crucial for microcirculation and may prevent thrombosis and other complications of the cardiovascular system. No statistically significant differences were found for AI, AMP, T½, plasma viscosity, or fibrinogen in the groups of winter swimmers who exercised in addition to cold water immersion (CWI + PE groups).

Plasma viscosity is dependent, among other parameters, on fibrinogen concentration, which increases with age (HAGER *et al.* 1994). KOVACS *et al.* 2006 observed an increase in fibrinogen level in the elderly which leads to increased blood viscosity and aggregation of red blood cells. However, fibrinogen levels can be reduced through physical activity (BRUN *et al.* 2007), which may explain the fact that plasma viscosity in physically active people is associated with lower fibrinogen levels. The AMP significantly decreased in people who participated in rhythmic exercises with music, while AI, T½, and fibrinogen levels remained unchanged (MARCHEWKA *et al.* 2015).

In our study, it was shown that under the influence of additional physical exercises there was a significant reduction in cortisol level. This could suggest that undertaking physical activity, and especially the intensity of the activity, has an impact on blood cortisol. However, some limitations may be caused by the following facts: there is a circulatory rhythm of cortisol secretion (blood was collected in the morning) and blood was collected shortly after finishing the exercise program.

CARDINALE *et al.* 2010 conducted a study on the impact of a one-time exercise done on a vibrating platform on the secretion of hormones in elderly people. The experiment was composed of 20 participants (9 men and 11 women) aged 66-85 years. Their level of hormones was examined immediately after the exercise, as well as after 1 and 2 hours post-exercise. It was observed that cortisol levels did not change under the influence of the applied exercise, however, the interaction of time and exercise was important (CARDINALE *et al.* 2010).

Although there are some limitations in the results of our study, we can confirm our hypothesis that physical exercise causes changes in biochemical and rheological parameters of blood in winter swimmers. Nevertheless, the topic demands further study in or-

der to check if a different intensity of exercise would yield different results.

## Conclusions

Moderate physical exercise has an influence on the level of cortisol in regular winter swimmers with osteoarthritis. Physical activity and winter swimming result in a higher elasticity of red blood cells. Plasma viscosity, fibrinogen, AI, T½, and AMP were not affected by exercise programs. These parameters are mainly affected by winter swimming.

## Acknowledgments

The authors would like to thank the winter swimmers of the Cracow Winter Club “Kaloryfer” for their participation in this project.

## Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Author Contributions

Research concept and design: M.S., A.T., B.P.; Collection and/or assembly of data: M.S., A.T., B.P.; Data analysis and interpretation: J.M.; Writing the article: M.S.; Critical revision of the article: M.S., A.M.; Final approval of article: M.S., A.T., B.P., A.M.

## References

- BORG G. A. 1982. Psychophysical bases of perceived exertion, *Med. Sci. Sports Exerc.* **14**: 377-382. <https://doi.org/10.1249/00005768-198205000-00012>
- BRUN J.F., CONNES P., VARLET-MARIE E. 2007. Alterations of blood rheology during and after exercise are both consequences and modifiers of body's adaptation to muscular activity. *Sci. Sports* **22**: 251-266. <https://doi.org/10.1016/j.scispo.2007.09.010>
- BRUN J.F., KHALED S., RAYNAUD E., BOUIX D., MICALLEF J.P., ORSETTI A. 1998. The triphasic effect of exercise on blood rheology: Which relevance to physiology and pathophysiology? *Clin. Hemorheol. Microcirc.* **19**: 89-104.
- CARDINALE M., SOIZA R.L., LEIPER J.B., GIBSON A., PRIMROSE W.R. 2010. Hormonal responses to a single session of whole-body vibration exercise in older individuals. *Br. J. Sports. Med.* **44**: 284-288. <https://doi.org/10.1136/bjism.2007.043232>
- CHRISTY R.M., BASKURT O.K., GASS G.C., GRAY A.B., MARSHALL-GRADISNIK S.M. 2010. Erythrocyte aggregation and neutrophil function in an aging population. *Gerontology* **56**: 175-180. <https://doi.org/10.1159/000242461>

- FEHER G., KOLTAI K., KESMARKY G., SZAPARY L., JURICKAY I., TOTH K. 2006. Hemorheological parameters and aging. *Clin. Hemorheol. Microcirc.* **35**: 89-98.
- GLOTH M.J., MATESI A. M. 2001. Physical therapy and exercise in pain management. *Clin. Geriatr. Med.* **17**: 525- 35. [https://doi.org/10.1016/s0749-0690\(05\)70084-7](https://doi.org/10.1016/s0749-0690(05)70084-7)
- HAGER K., FELICETTI M., SEEFRIED G., PLATT D. 1994. Fibrinogen and aging. *Aging* **6**: 133- 138. <https://doi.org/10.1007/BF03324226>
- JONSDOTTIR I.H., HOFFMANN P., THOREN P. 1997. Physical exercise endogenous opioids and immune function. *Acta Physiol. Scand. Suppl.* **640**: 47-50.
- KOVACS A., SZIKSZAI Z., VARADY E., IMRE S. 2006. Study on hemorheological parameters of oldest-old residents in the East-Hungarian city, Debrecen. *Clin. Hemorheol. Microcirc.* **35**: 83- 88.
- KULIS A., MISIOREK A., MARCHEWKA J., GŁODZIK J., TELEGLÓW A., DĄBROWSKI Z., MARCHEWKA A. 2017. Effect of whole-body cryotherapy on the rheological parameters of blood in older women with spondylarthrosis. *Clin. Hemorheol. Microcirc.* **66**: 187-195. <https://doi.org/10.3233/CH-160230>
- MARCHEWKA A., FÍLAR-MIERZWA K., DĄBROWSKI Z., TELEGLÓW A. 2015. Effects of rhythmic exercise performed to music on the rheological properties of blood in women over 60 years of age. *Clin. Hemorheol. Microcirc.* **60**: 363-373. <https://doi.org/10.3233/CH-131793>
- RODDY E., ZHANG W., DOHERTY M., ARDEN N.K., BARLOW J., BIRRELL F., CARR A., CHAKRAVARTY K., DISKSON J., HAY E., HOSIE G., HURLEY M., JORDAN K.M., MCCARTHY C., MCMURDO M., MOCKETT S., O'REILLY S., PEAT G., PENDLETON A., RICHARDS S. 2005. Evidence based recommendations for the role of exercise in the management of osteoarthritis of the hip or knee – the MOVE consensus. *Rheumatology* **44**: 67-73. <https://doi.org/10.1093/rheumatology/keh399>
- TELEGLÓW A., MARCHEWKA J., TABAROWSKI Z., REMBIASZ K., GŁODZIK J., ŚCISŁOWSKA-CZARNECKA A. 2015. Comparison of selected morphological, rheological and biochemical parameters of winter swimmers blood at the end of one winter swimming season and at the beginning of another. *Folia Biol. (Kraków)* **64**: 221-228. [https://doi.org/10.3409/fb63\\_3.221](https://doi.org/10.3409/fb63_3.221)
- TURCZYŃSKI B., MICHALSKA-MAŁECKA K., SŁOWIŃSKA L., SZCZĘSNY S., ROMANIUK W. 2004. Non-proliferative diabetic retinopathy and erythrocyte aggregation. *Medical News* **57**: 634-640.
- WOODWARD M., RUMLEY A., TUNSTALL-PEDOE H., LOWE G.D. 1999. Associations of blood rheology and interleukin-6 with cardiovascular risk factors and prevalent cardiovascular disease. *Br. J. Haematol.* **104**: 246-257. <https://doi.org/10.1046/j.1365-2141.1999.01158.x>