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Rheological and Morphological Properties of Blood vs. Vibration Exercises (Smovey®)—A Preliminary Study on Elderly Women

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Abstract: Background: Physical activity in elderly adults reduces the risk of numerous diseases, enhances their quality of life, and improves their physical performance and overall strength. This study aimed to evaluate the effects of smovey® exercise on morphological and rheological blood parameters in a group of women over 60 years of age. Methods: The study included 30 women aged 71.08 ± 6.41 years, with a control group of 15 age-matched women. Participants in the experimental group underwent a three-month smovey® training program, consisting of two 45 min sessions per week. The control group did not engage in any regular physical activity. Blood samples were collected from the experimental group before and after the training period, while in the control group, blood was collected once. Results: After three months of smovey® training, a statistically significant increase in red blood cell, hemoglobin, and platelet counts was observed. Smovey® training also enhanced erythrocyte deformability at the lowest shear force. Conclusions: Smovey® training leads to changes in the morphological properties of blood in elderly women, leading to increases in RBC, HGB, PLT, and MCHC indices. Additionally, smovey® training improves erythrocyte deformability at a shear stress of 0.30 [Pa], reducing the half-time of complete aggregation.

Keywords: smovey®; blood rheology; blood morphology; elongation index; aggregation index; elderly people

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Academic Editor: Takahiro Yamasaki

Received: 17 March 2025
Revised: 27 April 2025
Accepted: 28 April 2025
Published: 2 May 2025

Citation: Kiełtyka-Słowik, A.; Teleglów, A.; Gradek, J. Rheological and Morphological Properties of Blood vs. Vibration Exercises (Smovey®)—A Preliminary Study on Elderly Women. *Appl. Sci.* **2025**, *15*, 5058. https://doi.org/10.3390/app15095058

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1. Introduction

Physical activity is fundamental to physical, mental, and social well-being. Regardless of age, engaging in physical activity enhances the efficiency of internal organs, strengthens muscles, and slows down the aging process, as well as the progression of various diseases, including diabetes, obesity, osteoporosis, and circulatory and respiratory disorders [1]. Among elderly adults, the primary motivations for engaging in physical activity include improving motor coordination, balance, and overall well-being; fostering social interactions; and enhancing their ability to manage existing health conditions [2].

Currently, many institutions are actively offering a variety of physical activities for seniors, promoting the concept of healthy aging. Vibroswing-System (smovey®) is an innovative exercise technology that utilizes vibration. The device integrates contemporary knowledge with Chinese tradition. Vibration training is widely used in rehabilitation, medicine, and fitness to enhance muscle strength, raise the muscle core temperature, improve metabolism, and stimulate the lymphatic and circulatory systems. The exercise equipment consists of two rings with four metal balls placed inside and a handle. Each smovey® ring weighs 0.5 kg [3,4]. During exercise, as the user moves forward—and then

immediately in the opposite direction—steel balls roll inside the tube, generating pulsating vibrations in the user's hands. The vibrations are influenced by the natural and oscillatory movements of the rings at varying levels and directions. As such, they do not maintain a constant frequency, but instead produce a continuously changing, stochastic oscillatory signal. These vibrations are transmitted from the hands to the rest of the body [4].

Vibration exercises improve the functioning of the cardiovascular system due to a decrease in systolic pressure in the brachial artery and aorta, increase the blood flow after passive vibrations in the lower and upper body, and improve muscle strength and balance in the elderly population [5,6]. This form of physical activity brings better blood supply to the joint cartilage and increases the strength and elasticity of the ligaments and tendons [7]. An additional advantage is the increase in bone mineral density, which is better nourished and more resilient to fractures. This is particularly important in old age, because with age, the hormonal balance is disturbed, the bone structure weakens, and osteoporotic changes start to appear [8].

Vibration, as a mechanical stimulus, stimulates conditional and unconditional reflexes. The nervous system causes cramps and changes in muscle tone, lymph nodes, and blood circulation. Without the effect of stimulation, tension only occurs at a constant rhythm, while during the vibration of the stimulation, the muscles are mobilized and increase in strength and improve their efficiency [3]. Smovey® training is also an excellent example of fighting overweight, because it improves metabolism and firms tissues by increasing the energy expenditure during the exercises [9]. Smovey® training can also be used for people with Parkinson, multiple sclerosis, Alzheimer's disease, and depression and for oncological patients [10,11].

Hemorheology is a science that studies the effect of the pressure of flowing blood on its cellular elements and on the walls of blood vessels. This science focuses particularly on erythrocytes, and less often on leukocytes or platelets. In order to fulfill its function of nourishing and oxygenating every cell of the body, the erythrocyte must maintain excellent deformability and elasticity in order to squeeze through capillaries with a diameter of 1–2.5 μm (dimensions of a red blood cell: diameter 6–8 μm; thickness 1.7–2.5 μm; surface area 140 μm^2) [12].

The deformability of erythrocytes is influenced by several factors, such as the size and geometry of the vessels, the cytoskeleton, the intracellular viscosity, and the mechanical properties of the blood cell membrane [13]. Pathological conditions in our body are the cause of blood rheological disorders. These include hypertension, metabolic syndrome, diabetes, sickle cell disease, deficiency or the complete lack of glucose-6-phosphate-dehydrogenase, homozygous and heterozygous thalassemia, a lack of erythrocyte membrane protein, myocardial infarction, acute skin inflammation, and polycythemia [14–16].

The parameters that hemorheology also examines are hematocrit, blood, and plasma viscosity. The hematocrit value depends on the blood's ability to carry oxygen. Oncological patients have increased plasma viscosity, a reduced number of erythrocytes in the body, and a greater tendency of these to stick together, which results in impaired oxygen transport in the blood. Consequently, hypoxia in the microcirculation promotes thrombosis, tumor growth, and metastasis. The aforementioned blood viscosity is a measure of its internal friction, i.e., the resistance between the layers of fluid when it moves [17]. The blood viscosity depends on the number of morphological elements, hematocrit, the content and concentration of hemoglobin in the blood cells, the concentration of hemoglobin in erythrocytes, their volume and shape, as well as the level of proteins in the plasma [18–20]. Hemorheology examines the changes in the above parameters that occur depending on the diameter and geometry of the vessels, flow velocity, and shear rate.

Numerous studies have shown that physical exercise is also a factor that induces changes in the rheological and morphological properties of blood. Changes occur in the deformability of red blood cells and their ability to form or reduce erythrocyte aggregates [21–24]

The influence of vibrations induced by the smovey® device on erythrocyte deformability and morphological changes in blood has not been described to date. The aim of the present study was to assess the effect of smovey® vibration exercise on changes in the morphological and rheological blood parameters in a group of women aged over 60.

2. Materials and Methods

2.1. Group Characteristics

The assignment to groups was purposeful. The study group included people who declared their participation in a three-month smovey® training. The control group consisted of participants who declared that in the next 3 months, they would not undertake any regular form of training (individual or in organized groups). Of the 40 eligible individuals, 10 were excluded either due to a failure to meet the inclusion criteria or refusal to consent to participation.

The inclusion criteria for the study were as follows: age between 60 and 90 years, gender of woman, written informed consent to participate in the study, and the absence of significant cardiovascular and musculoskeletal diseases. The exclusion criteria were as follows: a failure to meet the inclusion criteria, musculoskeletal injuries within 12 months prior to the start of the project, unstable coronary artery disease, untreated hypertension, overt heart failure, post-myocardial infarction status, valvular defects, severe untreated cardiac arrhythmias, morbid obesity (BMI > 40), recent post-surgical conditions or hospital stays, and the presence of a pacemaker. Blood samples were collected at the beginning and end of the smovey® training period by a qualified nurse. All participants provided written informed consent to participate in the study.

The study group consisted of 30 participants aged 60–84 years. Before the commencement of training, each participant completed a basic questionnaire providing information about their age, height, and weight. The experimental group, which participated in smovey® exercises, included 15 women, while the control group also comprised 15 women. The average age in the smovey® training group was 71.08 $\pm$ 6.41, and in the control group, it was 69.78 $\pm$ 6.24.

The Bioethics Committee at the Regional Medical Chamber in Krakow officially granted permission to conduct the research (No. 204/KBL/OIL/2022).

2.2. Intervention

The training program involved a three-month exercise cycle using the Vibroswing-smovey® System. Under the supervision of a qualified instructor, study participants engaged in exercises twice a week for 1.5 h. The intervention consisted of moderate-intensity aerobic exercise. During the first week, participants were taught techniques for using the equipment and basic exercise variations.

Each training session consisted of three parts, the warm-up, main, and final phases, with all exercises being performed in upright positions. The sessions began with a 15 min general warm-up, including arm and trunk exercises, first without equipment, and then with the smovey® equipment. The main phase focused on strength training of the arms and trunk using smovey® equipment, lasting 60 min. Stabilization, balance, and coordination exercises were incorporated. Exercises included lateral and cross-swings in the frontal plane, as well as parallel and alternating side swings. The upper limb movements were coordinated with movements of the remaining parts of the body. The training concluded

with relaxation exercises and a 15 min massage using the smovey® device (smovey Gmbh; 4400 Steyr; Austria).

2.3. Study Methods of Morphological and Rheological Assessment

Blood samples of 10 mL were collected from study participants into Vacuette EDTA K2 tubes by a qualified nurse, in accordance with the applicable standards. In the study group, blood was collected at the beginning and after three months of smovey® training. In the control group, blood was collected once before starting smovey® training. Blood was drawn on an empty stomach in the morning from the antecubital vein. Morphological and rheological blood parameters were determined at the Blood Physiology Laboratory of the Central Research and Development Laboratory of the University of Physical Culture in Krakow and at the Department of Clinical Analytics and Biochemistry of the Institute of Oncology in Krakow.

The following blood morphology measurements were carried out: red blood cell count (RBC) [$10^6/mm^3$], hemoglobin (HGB) [g/dl], hematocrit (HCT) [%], mean corpuscular hemoglobin (MCH) [pg], mean corpuscular hemoglobin concentration (MCHC) [g/dl], mean corpuscular volume (MCV) [μm^3], red blood cell distribution width (RDW) [%], white blood cell count (WBC) [$10^3/mm^3$], platelet count (PLT) [$10^3/mm^3$], mean platelet volume (MPV) [μm^3], and platelet distribution width (PDW) [%].

The following blood rheological parameters were measured: erythrocyte aggregation index (AI) [%], amplitude and total aggregation range (AMP) [au], half-time of complete aggregation (T1/2) [s], and deformability parameter elongation index (EI). The measurements were taken using a LORCA analyzer (Laser-Optical Rotational Cell Analyzer, RR Mechatronics, Zwaag, The Netherlands). The tests were conducted according to the standard protocol: 30 min from the moment of material collection, at a temperature of 37 °C.

2.4. Statistical Analysis

All obtained data were coded by the authors in Microsoft Excel and then statistically analyzed in Statistica version 13.3 (StatSoft®, Tulsa, OK, USA). Descriptive statistics were calculated: mean (x) and standard deviation (SD). The normality of distributions was checked using the Shapiro–Wilk test. Data distribution analysis was performed using parametric tests—Student's *t*-test for dependent samples within a group and the same test for independent samples when performing comparisons within the groups. A statistical significance of $p < 0.05$ was adopted.

3. Results

We investigated a total of 30 women (15 from the study group and 15 from the control group). Basic anthropometric data of the study group and the control group (body weight and height) were recorded. The body mass index in the group before smovey® training was about 28.98 [kg/m^2], while after 3 months of training, it changed slightly to about 28.66 [kg/m^2]. In the control group, the body mass index was 28.17 [kg/m^2] (Table 1).

Table 1. General characteristics of the respondents.

Characteristics	Group Before Smovey® Activity; n = 15	Group after Smovey® Activity; n = 15	Control Group; n = 15
Age [years]	71.08 ± 6.41	-	69.78 ± 6.24
Body height [cm]	159.62 ± 5.89	159.62 ± 5.89	158.93 ± 5.09
Body mass [kg]	73.85 ± 13.62	73 ± 12.76	71.07 ± 11.51
Body mass index [kg/m^2]	28.98 ± 5.25	28.66 ± 4.94	28.17 ± 4.55

The studies conducted using the regular smovey® vibration exercise showed statistically significant changes in blood morphological properties. Statistically significant increases in the RBC, HGB, PLT, and MCHC were observed in the women after three months of smovey® training. Statistically significant decreases in the MCV were noted in the women after three months of smovey® training (Table 2).

Table 2. Intergroup comparisons of the mean values of indicators (before and after smovey® activity, and after smovey® activity vs. the control group).

Parameters	Group Before Smovey® Activity	Group After Smovey® Activity	*p* Value.	Control Group	*p* Value. (After Smovey® Activity vs. the Control Group)
WBC [10^9/L]	5.22 ± 1.21	5.41 ± 1.20	0.419	5.76 ± 1.87	0.564
RBC [10^{12}/L]	4.17 ± 0.24	4.46 ± 0.39	0.010 *	4.35 ± 0.21	0.385
HGB [g/dL]	12.24 ± 0.72	13.32 ± 1.32	0.002 *	13.47 ± 0.90	0.720
HCT [L/L]	39.05 ± 2.27	40.52 ± 3.82	0.093	40.03 ± 1.88	0.670
PLT [10^9/L]	228.38 ± 38.79	268.15 ± 54.26	0.000 *	241.29 ± 48.91	0.188
MCV [fl]	93.77 ± 4.36	90.85 ±2.91	0.000 *	92.00 ± 3.37	0.418
MCH [pg]	29.38 ± 1.60	29.71 ± 2.15	0.275	30.99 ± 2.03	0.124
MCHC [mmol/L]	31.42 ± 0.52	32.82 ± 0.74	0.000 *	33.68 ± 1.66	0.100
EI 0.30 [Pa]	0.04 ± 0.01	0.05 ± 0.01	0.014 *	0.05 ± 0.01	0.364
EI 0.58 [Pa]	0.10 ± 0.02	0.10 ± 0.01	0.894	0.10 ± 0.02	0.909
EI 1.13 [Pa]	0.19 ± 0.02	0.18 ± 0.02	0.509	0.18 ± 0.02	0.816
EI 2.19 [Pa]	0.29 ± 0.02	0.28 ± 0.02	0.432	0.28 ± 0.02	0.708
EI 4.24 [Pa]	0.38 ± 0.02	0.38 ± 0.01	0.880	0.37 ± 0.02	0.160
EI 8.23 [Pa]	0.44 ± 0.02	0.45 ± 0.01	0.383	0.43 ± 0.02	0.012 *
EI 15.96 [Pa]	0.50 ± 0.02	0.50 ± 0.02	0.887	0.45 ± 0.12	0.149
EI 31.04 [Pa]	0.55 ± 0.02	0.55 ± 0.03	0.860	0.53 ± 0.03	0.153
EI 59.97 [Pa]	0.59 ± 0.02	0.56 ± 0.13	0.375	0.56 ± 0.04	0.955
AI [%]	62.37 ± 4.67	64.65 ± 5.70	0.033 *	62.99 ± 5.24	0.437
AMP [au]	25.51 ± 2.43	21.11 ± 1.99	0.000 *	24.22 ± 1.78	0.000 *
T1/2 [s]	2.27 ± 0.50	2.02 ± 0.61	0.034 *	2.19 ± 0.56	0.470

* Significant difference ($p < 0.05$). WBC, white blood cell count; RBC, red blood cell count; HGB, hemoglobin; HCT, hematocrit; PLT, platelet count; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; RDW, red blood cell distribution width; MPV, mean platelet volume; PDW, platelet distribution width; EI, elongation index; AI, aggregation index; AMP, amplitude and total extent of aggregation; T1/2, aggregation half-time.

When analyzing the results for the rheological indicators, there were also changes. Comparing the information on the elongation index in the groups before and after regular smovey® vibration exercise, a statistically significant increase in the value was found only for EI 0.30 [Pa] in the group after smovey® exercises compared to the values before smovey® vibration exercise. In comparison with the group before smovey® vibration exercise, after smovey® exercises, the group showed a statistically significant increase in the AI [%]. Statistically significant decreases in the AMP [au] and aggregation half-time were noted in the women after three months of smovey® training (Table 2).

Analyzing the values of the elongation index in the control group and in the group after smovey® training, for EI 8.23 [Pa], statistically significant increase in values were observed in the women after smovey® training compared with the control group. In the remaining cases, no significant statistical differences were observed (Table 2).

Compared to the control group, studies conducted in women after 3 months of smovey® training showed a statistically significant increase in the AMP [au] (Table 2).

4. Discussion

The form of training that is performed in smovey® training, which utilizes vibrations, has not yet been described and explained in the context of morphological and rheological studies in elderly people. As a result of the aging process of the body, changes occur in the form of reductions in the number of red blood cells, the concentration of hematocrit, and hemoglobin, which can cause diseases related to the circulatory system. With age, the blood flow decreases, which can consequently lead to increased red blood cell aggregation [24]. During physical exercise, the RBC and the hemoglobin level increase, which improves the blood's ability to carry oxygen and nourish the body's cells [25]. The study results show that 3 months of smovey® training leads to changes in the rheological and morphological properties of blood. Increases in the RBC, HGB, PLT, MCHC, AI, and EI were observed at a shear stress of 0.30 [Pa], while decreases in the MCV, AMP, and T1/2 were noted. The aggregation index and the elongation index allow for the assessment of the rheological characteristics of blood. Rheological properties such as aggregation and deformation are important indicators of microcirculation. There is abundant information in the literature on situations in which hemorheological factors are impaired, contributing to the development of cardiovascular diseases, particularly in the elderly population. Their improvement may result in lower mortality and cardiovascular disease [26–29].

Our research confirms that after physical activity, there are increases in hematocrit and the number of red blood cells. However, the study authors emphasize that hemorheological changes should not impair the function of the circulatory system in healthy people but may already pose a threat to health in various pathophysiological conditions [30]. In the study by Marchewka et al., a group of senior women underwent 5 months of rehabilitation training in the form of rhythmic exercises. Morphological and rheological tests were performed, and an improvement in the RBC and the level of HCT, as well as the deformability of erythrocytes (EI) at a shear stress of 0.30 and 0.58 [Pa], and a decrease in the aggregation amplitude were observed [31]. Different results were presented in the study by Filar-Mierzwa et al., conducted on a group of elderly women participating in dance movement therapy exercises. As a result of 3 months of training, no statistically significant differences were observed in the RBC, PLT, WBC, MCHC, or MCV. However, changes in rheological parameters were confirmed, with an increase in erythrocyte deformability at EI 0.30 [Pa] and a shortening of the half-time of complete aggregation (T1/2) [32]. In the study by Awad et al., the association of general obesity, physical activity, and sleep hours with hemoglobin concentration and red blood cell parameters was assessed. Increased physical activity was found to be associated with higher HGB levels and RBCs [33]. In the study by Bobeuf et al., a 6-month resistance training program was used for seniors, whose hematological profile (red blood cells, hemoglobin, hematocrit, platelets, leukocytes, neutrophils, lymphocytes, monocytes, mean corpuscular volume, mean corpuscular hemoglobin, mean corpuscular hemoglobin concentration, and red blood cell distribution width) was examined. No significant differences were found in any of these parameters after training [34]. In the study by Strzelczyk et al., the influence of moderate physical exercise on selected blood parameters was examined in regular winter swimmers aged 45–68. A significant increase in erythrocyte deformability (EI) was observed in both women and men at higher shear stress values from 2.19 to 60.30 [Pa] [35].

In subsequent studies by Kabata-Piżuch et al., vibrotherapy was used in a group of women aged 60–70. After thirty vibration sessions, no significant statistical changes were observed; therefore, vibrotherapy did not disrupt the hematological balance. When analyzing the results of rheological parameters, a decrease in erythrocyte aggregation parameters, an extension of the half-life of complete aggregation (AI, T1/2), and a decrease in fibrinogen concentration were observed [36]. In a study by Kim et al., the effects of a

12-week resistance and aerobic training program were examined in a group of elderly men. It was found that training caused changes in RBC deformability and aggregation [37]. In the study by Sandor et al., the influence of long-term physical training on hemorheological parameters was examined in a group of elderly people. Following training, a slight decrease in HCT was observed, while significant reductions in blood viscosity and plasma viscosity were noted. The red blood cell aggregation indices and deformability parameters increased significantly [38].

Rheological blood tests, when considered alongside morphological blood parameters, provide valuable insights into the health status of elderly patients. Any changes in morphological parameters, as well as alterations in blood and plasma viscosity, may indicate underlying health issues.

Practical Applications:

It is worth emphasizing the role of hemorheology in the diagnosis and prevention of diseases such as atherosclerosis, hypertension, diabetes, thrombosis, and hyperlipidemia.

The results of our studies show the benefits resulting from changes in morphological and rheological blood parameters when using smovey® training. These exercises are safe for elderly people and improve the circulatory system. Introducing regular smovey® training sessions to facilities where seniors stay (retirement homes) and which they use as part of their active leisure time (universities of the 3rd century) would improve their psychophysical condition and quality of life, which could ultimately contribute to successful aging.

Study limitations:

This study has some limitations that should be considered. One key limitation is the relatively small number of participants in the experimental group, as well as the restriction to elderly individuals. The small sample size may reduce the statistical power. Future studies should include larger and more diverse groups of participants to provide more comprehensive insights into changes in morphological and rheological blood parameters.

5. Conclusions

The following conclusions were formulated:

1. Smovey® training caused changes in the morphological properties of blood, leading to increases in the RBC, HGB, PLT, and MCHC indices, and decreased the MCV index in the group of elderly women.
2. Smovey® training affects the rheological parameters of the blood of elderly women, improving the deformability of erythrocytes at the lowest shear stress values and shortening the half-life of complete aggregation.
3. Smovey® training is a simple, cheap, and accessible tool that can be used regularly to improve the rheological parameters of the blood of older women.

Author Contributions: Conceptualization, A.K.-S.; data curation, J.G.; formal analysis, A.K.-S. and A.T.; investigation, A.K.-S. and J.G.; methodology, A.K.-S. and A.T.; supervision, A.K.-S. and A.T.; writing—original draft, A.K.-S.; writing—review and editing, A.K.-S. All authors have read and agreed to the published version of the manuscript.

Funding: The study was funded by the University of Physical Culture in Krakow as part of statutory research funding–maintaining research potential for 2022/23 (no. 308/BS/INP/2023)–and by the Minister of Science under the Regional Excellence Initiative Programme based on agreement no. RID/SP/0027/2024/01 of 05.01.2024.

Institutional Review Board Statement: The Bioethics Committee at the Regional Medical Chamber in Krakow officially granted permission to conduct the research (consent number: No. 204/KBL/OIL/2022; from the day 16.09.2022 r.).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable reques.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AI	aggregation index;
AMP	amplitude and total extent of aggregation;
EI	elongation index;
HCT	hematocrit;
HGB	hemoglobin;
LORCA	Laser-Optical Rotational Cell Analyzer
MCH	mean corpuscular hemoglobin;
MCHC	mean corpuscular hemoglobin concentration;
MCV	mean corpuscular volume;
MPV	mean platelet volume;
PDW	platelet distribution width;
PLT	platelet count;
RBC	red blood cell count;
RDW	red blood cell distribution width;
T1/2	aggregation half-time;
WBC	white blood cell count.

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