Pol J Aviat Med Bioeng Psychol 2019; 25(4): 13-20
DOI: 10.13174/pjambp.07.09.2022.02

ORIGINAL ARTICLE

SAFETY OF THE USE OF HIGH-ALTITUDE PROTECTION SUITS IN PATIENTS WITH NEUROLOGICAL DISORDERS IN KINESITHERAPY

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Source of support: Own sources.

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Abstract: HAP (High-Altitude Protection) suits were originally developed to protect the bodies of flight personnel from the effects of low atmospheric pressure. At a later stage of their development, they were supplemented with a system to prevent the negative effects of gravitational acceleration. A new and very different application of HAP suits is their use in the kinesitherapy process for patients with neurological deficits. However, due to the possibility of cardiovascular overload and a potentially dangerous increase in blood pressure, studies have been conducted to observe the occurrence of increased blood pressure. The study was conducted on a group of 39 patients with various neurological deficits during a five-occupation therapy session. Previously published results obtained for 17 healthy subjects (control group) were used for comparison [2]. The WUK 90 version of the HAP suit was used during the therapy. The compared results for the control and experimental groups are similar to each other AND show no increase in blood pressure.

Keywords: High-Altitude Protection suit, kinesitherapy, cardiovascular load, therapy safety

Figures: 5 • **Tables:** 4 • **References:** 16 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2022 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

High Altitude Compensation Suits (HAP suits), are protective garments used by pilots when flying at high altitudes, which are sometimes also called pressure suits. This equipment is designed to protect the aircrew in emergency situations involving exposure to very low atmospheric pressure (e.g., loss of cabin pressure at high altitude) as well as due to the overloading that occurs during dynamic flight maneuvers.

The first suits for high-altitude flight were developed in the 1930s and were designed to protect against reduced atmospheric pressure, while versions that protected the pilot from overloading were created in the 1940s and their development is taking place all the time. This is related to the achievement of ever-increasing altitudes both in combat flights and also in civil aviation. The need for mechanical compression on the user's body is due to two reasons. First, at altitudes above about 10,000 meters, breathing even 100% oxygen at atmospheric pressure does not meet the needs of the human body, and oxygen must be supplied at a pressure greater than the surrounding atmospheric pressure. Such a condition, known as Positive Pressure Breathing (PPB), can lead to damage to the lung tissue and chest wall, so there is a need for external pressure on the chest wall to balance the intrapulmonary pressure [16]. Second, at even higher altitudes – around 18–19,000 m (60–62,000 ft) the risk of boiling body fluids is present. At a pressure of about 47 mm Hg, body fluids begin to boil at human body temperature, which would quickly lead to tissue destruction [14]. To protect life at such heights, both positive pressure breathing and external body pressure are absolute safety requirements [12].

In addition to being a safety device, protective suits are sometimes used in ways other than their original application, such as raising blood pressure in an upright position after exposure to prolonged microgravity, or in kinesitherapy as assistive devices for people with antigravity muscle deficits [5]. An additional advantage of applying pressure to the body is the muscular and proprioceptive stimulation that continues during the therapy session [10].

The general structure of the suit is shown in Figures 1-2, and its operating principle is shown in Figure 3.

The main threat to the safety of HAP suits is the increase in pressure and breathing difficulties caused by mechanical pressure on the wearer's body, which results in high intra-tissue pressure. The use of pneumatic assemblies exerting force on the body in kinesitherapy is not common, and the bibliography related to this topic is very sparse. It primarily concerns the use of lymphatic drains in the upper or lower extremities, but the systems used do not cover the patient's entire body. The only similar system is used in kinesitherapy based on the "Atlant" suit [1,2]. We found no publications on the safety of their use, especially with regard to possible cardiovascular overload of patients. Some available data [8] suggest that pressures below 70 mm Hg are perfectly safe and do not cause a significant increase in blood pressure [1,2,4,11].

As part of a broader project in the field of kinesitherapy, we sought to investigate whether using a HAP suit that will be inflated to pressures in the range envisioned for future experiments is safe in terms of the cardiovascular load on participants' bodies. The hypothesis made on the basis of previous studies on the experimental group allowed us to assume that the results obtained would confirm the absence of an increase in blood pressure in patients with neurological deficits expressed by an increase in HR and RR within safe limits.

MATERIAL AND METHODS

In the study presented here we used the HAP suit, manufactured by (Air-Pol, Legionowo, Poland), as a high-altitude compensation suit in the WUK-90 version. It is acapstan type suit. In this system, the generation of pressure on the body is accomplished by inflating rubber hoses that increase the pressure on the body through expansion bands sewn to the fabric of the suit (Figure 3). In addition, the suit is equipped with an abdominal bladder whose mechanism involves exerting pressure on the lower abdomen and front part of the pelvis. HAP suits must be properly fitted to the body to serve their purpose. This applies to the proper selection of the suit due to the height of the wearer as well as takes into account the wearer's physique. However, the precise adjustment of the suit relies on the use of polypropylene laces. Fastening the suit is done with zippers. To meet the needs of the ongoing research, design changes were made, such as reducing the number of lacing sequences and closing pressure circuits in such a way that exercises could be performed. In order to distinguish the High Altitude Compensation Suit – WUK 90 from the suits we adapted, the development of the adapted suit was given the name R-WUK (Figure 2).

The research was conducted in three stages. Stage one consisted of a study with one patient

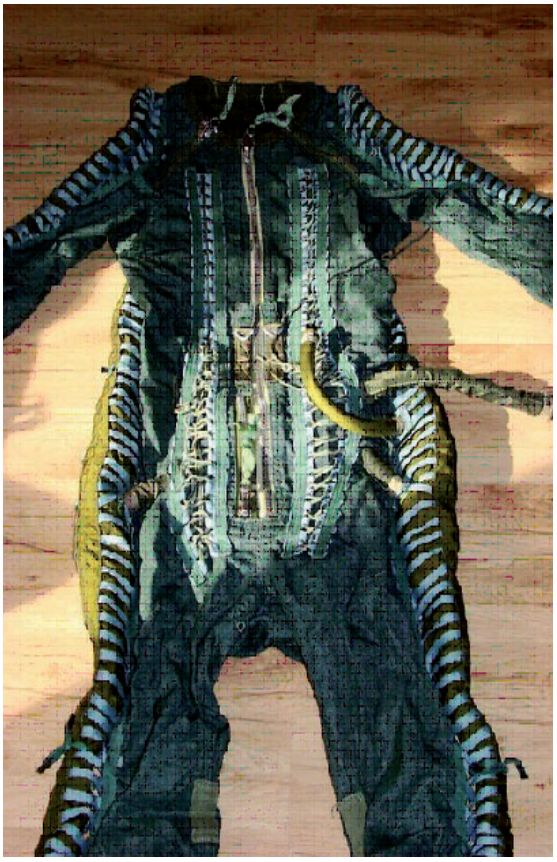

Fig. 1. WUK protective suit.

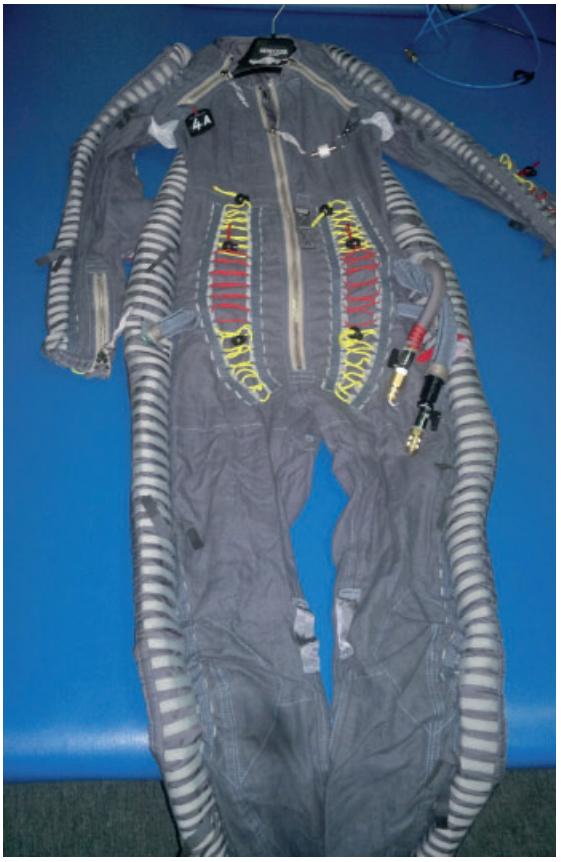

Fig. 2. R-WUK protective suit used in research.

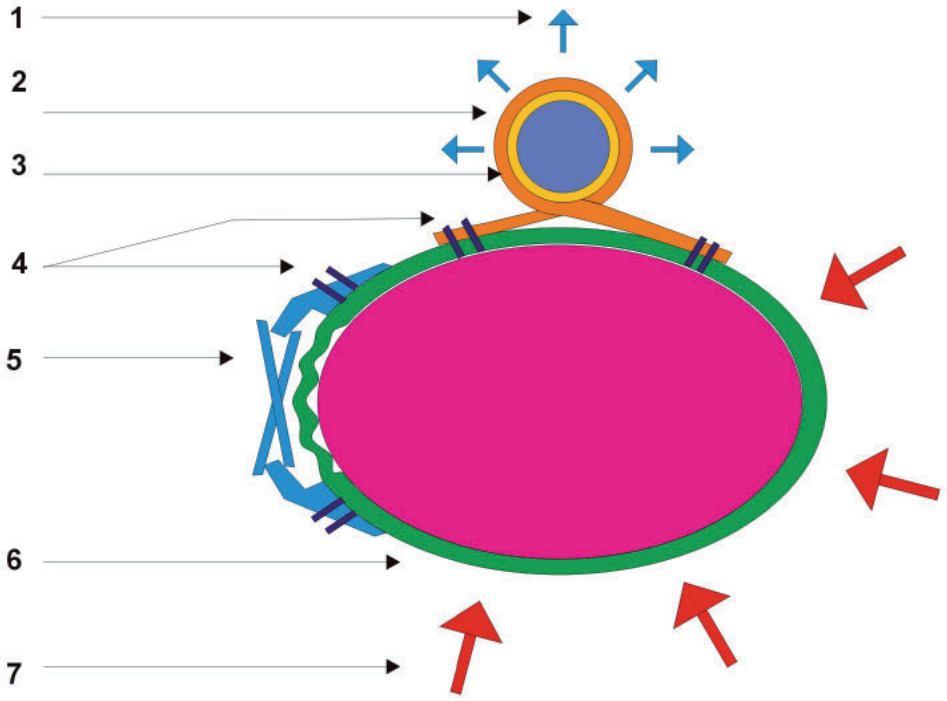

Fig. 3. Capstan suit operation principle.

1 – force of the pneumatic system, 2 – rubber tube supplying pressure, 3 – expansion (Capstan) tapes, 4 – local fastening, 5 – local lacing, 6 – fabric of the suit, 7 – force of the fabric on the tissues.

who, as a healthy person, was subjected to Bruce's protocol. The test was significant enough that, according to the hypotheses put forward, it should not cause the body's defensive reaction of increasing the patient's blood pressure when the patient works in the suit. This experiment confirmed the hypothesis and opened the way for further steps. Stage two consisted of a study of healthy patients who were subjected to the same rigors of exercise during therapy, according to the guidelines for teaching patients with neurological deficits. The medical experiment included a group of 17 healthy volunteers, including eight women and nine men. The mean age of the control group was 29.5 ± 4.69 years; the range was 23 to 41 years. Systolic and diastolic blood pressure (using an OMRON™ R7 blood pressure monitor), arterial blood saturation SpO2 (using a pulse oximeter finger measurement) were measured in each participant. The results were recorded and analyzed using paired-tests. Blood pressure was measured 5 min before the HAP suit was put on, followed by RR and SpO2 measurements at 3 min intervals. Each test lasted 24 minutes. The last measurements were taken 5 minutes after the HAP suit was removed. The results of the study have been previously described [2]. This study formed the basis for conducting the rest of the experiment with patients with neurological deficits and served as the control group for the rest of the study.

The experimental group consisted of 39 people, including 21 women and 18 men. The average age of the group was 37.3±SD=12.6. This includes a mean age for women of 35.8±11.4 years and for men of 39.1±13.6 years. Those in the experimental group could not suffer from hypertension unless they were under constant medical supervision. The age structure of the experimental group is shown in Table 1. The group included patients from: MS (multiple sclerosis) – 7 people, MPD (cerebral palsy) – 12 people, STROKE (condition after ischemic stroke) – 2 people, TMOR (condition after removal of brain tumor) – 1 person, INJURY – (condition after craniocerebral trauma) – 4 people, URK (spinal cord injury) – 4 people, OTHER (other neurological entities with vague etiology or occurring singly) – 4 people. The structure of the disease units is shown in Table 2.

Each participant had their systolic and diastolic blood pressure measured (using an OMRON R7 blood pressure monitor). Results were recorded and analyzed using paired t-tests. Blood pressure measurements were taken up to 5 minutes before the suit was inflated and up to 5 minutes after the R-WUK suits were exercised. RR measurements were entered in the test sheet. Participants in the study performed a minimum of 5 treatment units, during which blood pressure parameters were monitored. At the same time, kinesitherapy exercises using therapeutic methods such as PNF and NDT Bobach were performed during the therapy session [3,6,9,10].

Previously published data for 17 healthy volunteers who performed one full kinesitherapy session using the R-WUK 90 version of the HAP suit was used as a control group [2]. Mean age of the control group was 29.5 ± 4.69 years (age span was from 23 to 41 years). Eight females and nine males constituted our control group. The Ethics Committee for Human Research at the Military Institute of Aerospace Medicine in Warsaw has issued written approval No. 13/2015 to perform research in accordance with the Helsinki Declaration of 1975, as amended in 2020. Each participant signed a state-

Tab. 1. Age structure of the experimental group.

Age	0–18	18–24	25–30	31–40	41–50	50+
Women	1	3	4	6	4	3
Men	2		4	5	3	4
Total	3	3	8	11	7	7

Tab. 2. Disease entities of the experimental group: MPD – Cerebral Palsy, MS – Multiple Sclerosis, URK – Spinal Cord Injury, B INJURY – Traumatic Brain Injury, STROKE – Ischemic Stroke, OTHER – other disease entities.

Unit	MPD	MS	URK	B INJURY	STROKE	OTHER
Women	7	8	1	1	0	4
Men	6	4	1	1	2	4
Total	13	12	2	2	2	8

ment of informed consent and was informed that he or she could discontinue participation at any time. Participants were volunteers and were not paid for their participation in the research presented.

RESULTS

As a first step, a study was conducted on the control group, which consisted of healthy subjects. Seventeen subjects and one subject were tested using a treadmill according to the Bruce protocol [7]. The results of this study were reported in an earlier publication [2]. A group of these volunteers served as a control group for further study. The study was then conducted on patients with neurological deficits. Both studies were approved by the Ethical Committee for Human Research at the Military Institute of Aviation Medicine in Warsaw. Due to the fact that if there was an increase

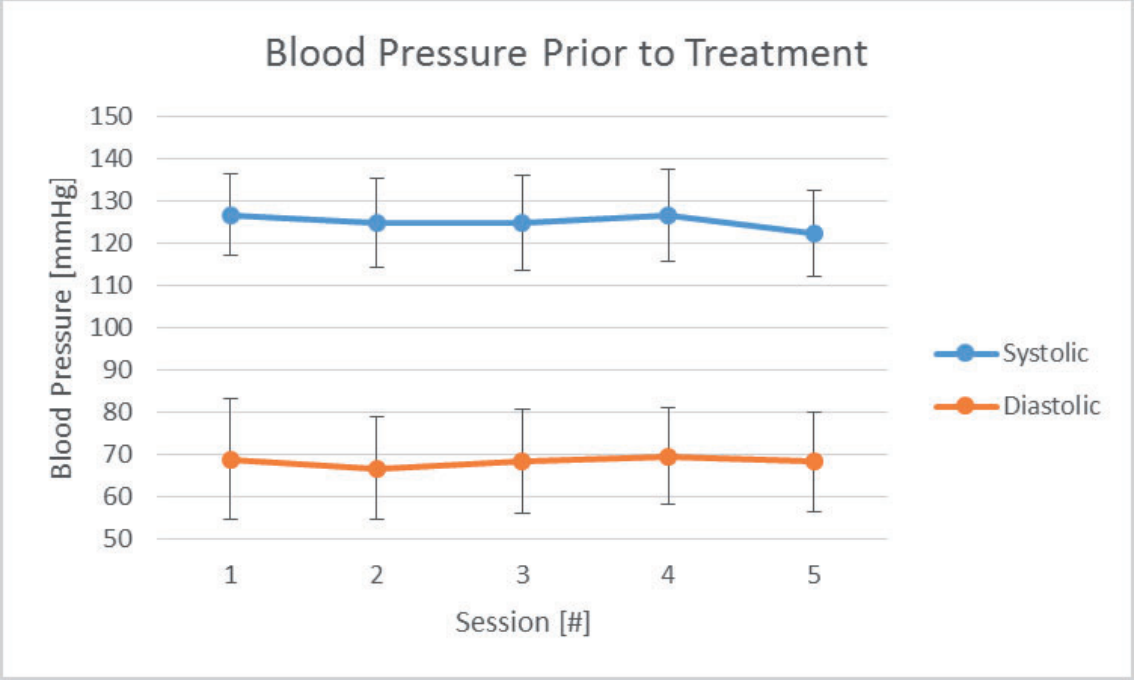

Fig. 4. Averaged initial pressures of the SYS and DIA experimental groups.

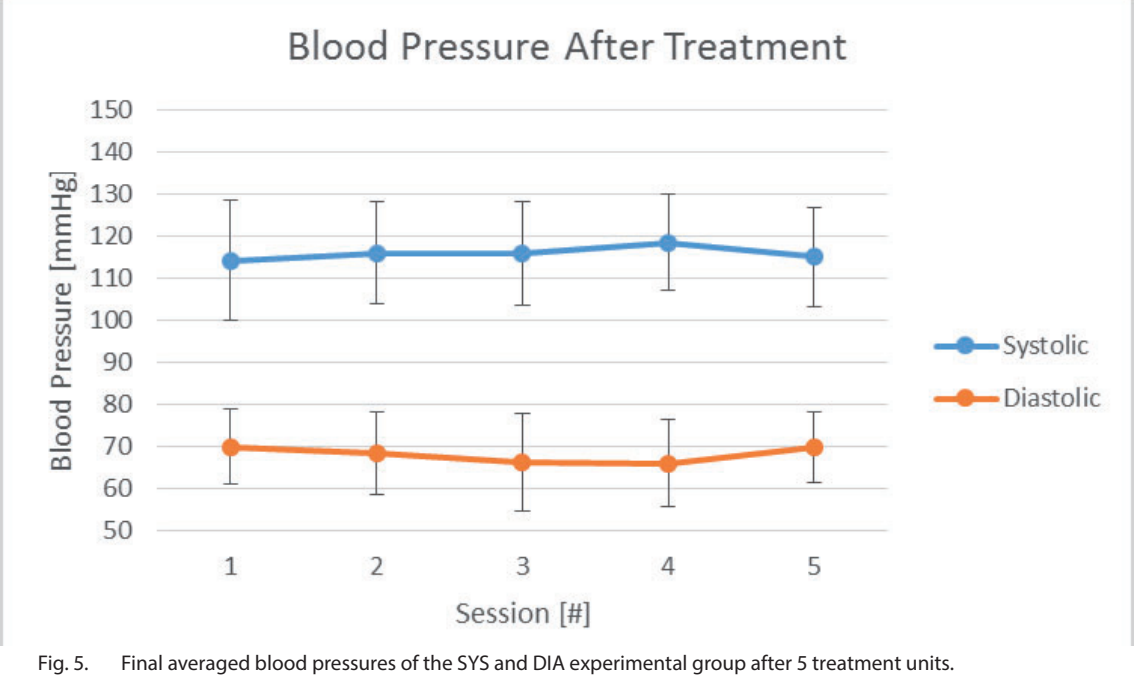

Fig. 5. Final averaged blood pressures of the SYS and DIA experimental group after 5 treatment units.

Tab. 3. Summary of averaged blood pressure values in therapeutic units.

	SYS (arithmetic mean)	SYS 1 (arithmetic mean)	DIA (arithmetic mean)	DIA 1 (arithmetic mean)
Activity 1	126.56	130.16	79.06	79.66
Activity 2	125.7	128.43	77.73	79.36
Activity 3	124.8	129.16	76.76	77.66
Activity 4	128.4	130.2	78.93	76.93
Activity 5	122.13	127.5	78.66	78.4

SYS – Systolic pressure measured before activity, SYS 2 – Systolic pressure measured after activity, DIA – Diastolic pressure measured before activity, DIA 2 – Diastolic pressure measured after activity.

Tab. 4. Comparison of the results of averaged blood pressure values for the control group (Kontr) and the group of patients with neurological

	SYS (arithmetic mean)	SYS 2 (arithmetic mean)	DIA (arithmetic mean)	DIA 2 (arithmetic mean)
Ex Group	125.5	129.1	78.2	78.4
Kontr Group	119.9	119.6	73.1	73.3

SYS – Systolic pressure measured before activity, SYS 2 – Systolic pressure measured after activity, DIA – Diastolic pressure measured before activity, DIA 2 – Diastolic pressure measured after activity.

in blood pressure for those with neurological deficits, it would also persist for a longer period of time after the activity ended, so the measurement test was performed before and immediately, i.e. up to 5 minutes after the activity ended. Participants in the program performed exercises to improve eye-motor coordination, balance exercises, and the realization of proper movement patterns in large motor skills. Each patient performed a therapy session consisting of min. 5 therapeutic units. The test results were entered after each treatment unit. A total of 362 hours were conducted with neurological patients using the R-WUK suit. The averaged results are shown in Figures 4 and 5 and Table 3. While comparing the results of the control group with the experimental group Table 4.

The most significant fact is that in none of the cases studied, regardless of age or disease entity, systolic blood pressure did not exceed SIS=160 mmHg, or stage II hypertension, assuming that patients with blood pressure above 140 mmHg were not allowed to exercise. This means that the maximum pressure spike did not exceed 20 mmHg. The highest value reached during the study was 158 mmHg in a patient with MPD who was very agitated at the first activity [15].

DISCUSSION

The main safety concerns associated with the use of compression devices, especially if they involve the chest area, imply an increase in blood pressure resulting from the addition of mechanical external pressure to the "normal" blood pressure generated by the heart. In the physiological state, blood pressure is regulated at the appropriate level by the carotid baroreceptor reflexes. The stretching of the walls of the carotid arteries caused by elevated blood pressure activates cardiac inhibition, mainly through the vagus nerve pathway. In the opposite situation (lowering blood pressure) parasympathetic inhibition is present on the baroreceptor by blocking the influence of the vagus nerve, thereby increasing cardiac output. This phenomenon is carefully studied during exposure with acceleration directed from the head toward the lower extremities (+Gz) in aircraft flight or in an overload centrifuge. This is quite a strong reflex, allowing the human body to compensate for the backlog of blood in the lower half of the body to about four times the gravity on Earth (+4Gz). In the experiments described in this article, we wanted to test whether the potential of this reflex is sufficient in the opposite direction, i.e., whether the decrease in cardiac output under elevated pressure conditions is sufficient to keep peripheral blood pressure from exceeding safe values. Due to the systemic nature of the reflex, we chose to measure blood at the wrist instead of standard blood pressure measurements, which are more technically and equipment-intensive and allow the free movement necessary for therapeutic exercises. Experience from centrifuge exposures proves that the use of altitude-compensated limb pressure measurement is sufficient

to assess blood pressure at both the cardiac and cerebral levels.

All the measurements performed confirmed that the use of the WUK-90 protective suit (HAP suit) in its adapted R-WUK version is safe in terms of cardiovascular parameters within the range of pressures used in the experiments. We found no increase in blood pressure, which could be considered harmful, for the participants. The small difference in initial and final pressures in the study is related to the age difference in the control and experimental groups as well as due to the specificity of neurological damage in the experimental group.

The results suggest that increasing physical pressure on the body is effectively corrected by the body's homeostatic system. Cardiovascular reflexes from the baroreceptors are sufficient to limit the increase in blood pressure resulting from the action of the suit's mechanical pressure on the chest. Our participants also reported no respiratory problems, which is another good predictor to conclude that the therapeutic use of the WUK-90 protective suit (HAP suit) adapted as R-WUK for kinesitherapy is a safe alternative to the "normal" sets of exercises planned to be performed in patients' therapy.

AUTHORS' DECLARATION:

Study Design: Maciej Abakumow, Paulina Zielińska, Krzysztof Kowalczuk. **Data Collection:** Maciej Abakumow, Paulina Zielińska, Krzysztof Kowalczuk. **Manuscript Preparation:** Maciej Abakumow, Paulina Zielińska, Krzysztof Kowalczuk. The Authors declare that there is no conflict of interest.

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Cite this article as: Abakumow M, Zielińska P, Kowalczuk K. Safety Of The Use Of High-Altitude Protection Suits In Patients With Neurological Disorders In Kinesitherapy. Pol J Aviat Med Bioeng Psychol 2019; 25(4): 13-20. DOI: 10.13174/pjambp.07.09.2022.02