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How posture influences venous blood flow in the lower limbs: results of a study using photoplethysmography

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Prolonged standing or sitting is one of the factors for chronic venous insufficiency. The aim of the study was to determine the impact of static load of the lower limbs on the functioning of the venous system. The study included 10 healthy young participants, with no peripheral venous disease. All participants took part in examinations in two variants: variant 1, sitting for 20 min with the lower limbs bent in the knee joints at 90°; variant 2, standing for 20 min with no additional load. Before and after each test, the venous refilling time (VRT) was determined using photoplethysmography. Statistical analysis demonstrated that the VRT was significantly shortened only after application of variant 2. Furthermore, even variants with small loads applied to healthy young participants can induce in them effects on the parameters describing the peripheral circulation.

Keywords: chronic venous insufficiency; lower limbs; occupational factors; posture; standing; sitting; Doppler ultrasound; photoplethysmography

1. Introduction

There are more veins than arteries, so the venous system has a much larger cross-sectional area. This results in a much larger volume available for blood storage. Indeed, veins are known as low-pressure storage reservoirs of blood. Under normal physiological conditions, the venous system contains about 75% of the total blood volume in the systemic circulation. For this reason, veins are often referred to as capacitance vessels.

Venous diseases are present in more than half of the population in developed countries. Chronic venous insufficiency (CVI), which is permanent blockade of the venous blood outflow from the lower limbs, is their most common form [1]. Because of its incidence, the illness is considered a social disease. CVI incidence among adult Poles is estimated to vary from 38.33% among men to 50.99% among women [2,3]. The social cost of CVI, taking into account sick leave, diagnostic examinations, hospitalization and surgical treatment, is comparable with the treatment of diseases commonly considered more serious, such as, e.g., cardiovascular diseases [4]. The root cause of the disease and of its sequelae is lack of prevention, resulting from insufficient knowledge on the risk factors for this disease, e.g., age, female gender, family history of the disease, congenital anomalies of venous vessels, pregnancy, being overweight, constipation, hormonal changes, high ambient temperature as well as long periods spent sitting or standing, including those related to occupational activities [5,6]. While sitting and especially standing, an increased hydrostatic pressure in the lower limbs causes damage to venous walls including valves. The important relation between posture adopted during work and the development and/or exacerbation of symptoms of CVI has often been studied [7–9]. However, this research usually focused on elderly persons. Because age is one of the main factors causing an increased incidence of CVI, theories about the occupational factors leading to this disease were limited in those cases. Persons of different age, including relatively young persons, participated in this study, and the main inclusion criterion was a minimum of 5 years of standing or sitting work.

As the consequences of a non-diagnosed and untreated CVI are very serious, and the number of workstations with standing and sitting posture continues to increase, undertaking studies concerning the incidence of CVI among individuals working in such conditions and defining the factors which can have influence seems justified and topical.

The aim of the study was to determine the impact of static load of the lower limbs during standing and sitting on the functioning of the venous system of the lower limbs in young persons, with no peripheral venous disease in their medical history.

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2. Methodology

2.1. *Study group*

The study was conducted in a group of 10 participants of mean (*SD*) age 28.3 (1.70) years, meeting the following criteria:

- aged 20–30 years;
- male;
- body mass index (BMI) within the normal weight category;
- negative family history of CVI of the lower limbs;
- no features of CVI of the lower limbs in diagnostic tests.

This study was approved by the ethics committee of the Medical University of Warsaw, Poland. Written informed consent was obtained from each participant.

2.2. *Methods*

2.2.1. *Preliminary examination*

The participants were subjected to a preliminary diagnosis of the venous system of the lower limbs using Doppler ultrasound. Thanks to its significant sensitivity and specificity, noninvasiveness and universal availability, Doppler ultrasound is the primary test method in diagnosing diseases of the venous and arterial system [10–13]. A Doppler ultrasound examination using a continuous wave method is the simplest technique for evaluating blood flow in the vessels. A carefully performed examination can in most cases determine the cause of venous insufficiency of the lower limbs. Currently, it is considered a good tool for initial screening diagnostics of the venous system.

The Doppler ultrasound examination of venous vessels of the lower limbs was conducted using a MyLab 60 device (Philips, The Netherlands), with a linear probe of a frequency of 4–13 MHz, by a physician specializing in diagnostic imaging according to his own research methodology.

Persons, in whom no features of CVI of the lower limbs were found as a result of the performed diagnosis, were subjected to the actual study using photoplethysmography.

2.2.2. *Photoplethysmography*

Photoplethysmography is increasingly used not only to assess the severity of CVI and to monitor the progress of its treatment, but also in healthy persons to assess the response to external stimuli [14–17]. This method is non-invasive, based on the principle of determining optical properties of a skin fragment. For this purpose infrared light, invisible to the eye, is emitted to the skin fragment. Depending on the instantaneous blood volume within the skin fragment, a larger or smaller amount of light is absorbed. As a result, the amount of reflected light corresponds to local variations in blood volume. To evaluate the venous system using photoplethysmography, the venous reflux test, a tip-toe test in which the venous refilling time (VRT) is estimated, is most commonly used [18,19]. VRT is defined as the refilling time of the venous bed to baseline after effort, which makes it possible to assess the severity of venous insufficiency. The venous refilling test is performed on both calves. A photoplethysmographic probe is placed on the skin using a special band a few centimeters (max. 8–10 cm) above the medial ankle. During the test, the patient is sitting, with the lower limbs resting on the ground and bent in the knee joints at 110°. Once a stable record is obtained, the signal is reset, and subsequently the patient performs rhythmic dorsiflexions and plantarflexions of the foot, which results in drainage of venous plexuses of the skin.

After performing a series of dorsiflexions the participant must remain at rest for a while. The device then measures the VRT. Under normal conditions, the VRT is at least 25 s. If it is shorter, this means that during the test a portion of the blood remained in venous vessels of the lower limbs and was not pushed upward because of an insufficiency of the venous valves (damaged venous valves do not protect against a backflow of the blood in the venous system).

The photoplethysmographic examination was conducted using a Rheoscreen light device (Medis, Germany).

2.2.3. *Procedure*

In each participant a venous refilling test was performed in triplicate and the VRT was determined before and after two variants of the study (a total of 60 tests were performed): variant 1, sitting with the lower limbs bent in the knee joints at 90°; variant 2, standing with no additional load.

The tests were performed at a computer workstation adapted to both sitting and standing postures (a computer table with the top surface adjustable between approximately 70 and 110 cm). The time that the participants remained in different postures was 20 min, during which they were asked to copy a set text using a computer. The minimum interval between tests with the same participant was 60 min. The conditions for the participation is the study included at least 30-min adaptation to room temperature and no alcohol consumption, drinking coffee or strong tea, or smoking cigarettes on the day of the study (these factors can modify VRT). Remaining at rest for several minutes before starting the test was also a prerequisite.

2.3. *Statistical analysis*

The statistical analysis of the test results was performed using Statistica version 9.0, employing Student's *t* test.

3. Results

Table 1 summarizes the results of the VRT for the 10 participants in variant 1. No statistically significant difference

Table 1. Venous refilling time (VRT) in variant 1 ($n = 10$).

	Variant 1					
	L			R		
VRT (s)	Before	After	*p*	Before	After	*p*
M	54.2	56.7	*ns*	54.8	55.5	*ns*
SD	5.45	8.56		8.02	9.79	
Range	44.5–66.1	40.1–74.0		40.6–69.9	42.6–72.3	

Note: L = left lower limb; R = right lower limb.

Table 2. Venous refilling time (VRT) in variant 2 ($n = 10$).

	Variant 2					
	L			R		
VRT (s)	Before	After	*p*	Before	After	*p*
M	61.8	55.5	<0.05	64.2	58.1	<0.05
SD	8.03	8.34		8.78	10.0	
Range	50.7–77.0	43.1–72.0		44.2–77.1	37.2–74.9	

Note: L = left lower limb; R = right lower limb.

between the mean values of VRT before and after variant 1 was observed.

Table 2 summarizes the results of the VRT for the 10 participants in variant 2, indicating statistical significance ($p < 0.05$).

4. Discussion

The aim of the study was to determine the impact of static load of the lower limbs during standing and sitting on the functioning of the venous system of the lower limbs in young persons, with no peripheral venous disease in their medical history.

Because CVI of the lower limbs is a disease of a multifactorial etiology, and older age, female gender and hereditary factor play an important role in its development, only young male participants, with no family history of this disease, took part in the study. In this group of participants, diagnostic examinations using Doppler ultrasound were performed.

As a result of diagnostic tests, 10 men, mean (*SD*) age 28.3 (1.70) years, with no features of CVI of the lower limbs qualified for the study. These participants took part in the study conducted with photoplethysmography. Each participant was tested three times in two variants: variant 1, sitting with the lower limbs bent in the knee joints at 90°; variant 2, standing with no additional load.

The most commonly used test to evaluate the venous system using photoplethysmography is the venous reflux test, in which the VRT, or the refilling time of the venous bed to baseline after effort, is measured. Under normal conditions, this lasts for at least 25 s. If the VRT is shorter, we can talk about venous insufficiency.

Repeated differences in the values of VRT between the two limbs in several consecutive examinations may also be a sign of the beginning of venous insufficiency of one of the limbs, long before the appearance of clinical symptoms of the insufficiency.

Photoplethysmography with a determination of VRT has been widely used in the examinations of patients with venous insufficiency to determine the severity of this insufficiency. The VRT is much less used in healthy participants, e.g., to assess changes in response to an external factor. Jasiński et al. [20] assessed changes in the values of VRT in a group of healthy women over 50 years of age in response to an 8-week regular physical activity – Nordic walking in one subgroup and water aerobics in the other. A statistically significant increase in VRT for both lower limbs was reported for the women practicing Nordic walking. Similar changes were not observed after 8 weeks of water aerobics.

In the present study, VRT was also assessed in healthy participants, with no features of CVI. In the baseline measurement, prior to the application of the respective variants, normal VRT values were obtained for each participant in each of the three tests. Moreover, no disproportion in the values of VRT between the right and the left limbs in any of the participants was recorded.

Considering the young age of the participants and their good health, as well as the conditions of the study characterized by small load, it was assumed that the values of VRT in the participants should not decrease below normal values after the application of the two variants. Indeed, in none of the participants and after none of the studies did the VRT decrease below 25 s.

However, it was observed that the VRT for 9 out of 10 participants decreased after using variant 2 of the study. The VRT decrease was related to both lower limbs and occurred in each of the three tests, which were applied to each of the 9 participants in this variant. In the case of one of the participants, the VRT during the two first tests in this variant increased, while during the third test it remained practically unchanged.

Statistical analysis demonstrated that a decrease in VRT after variant 2 as compared with baseline was statistically significant in the participants.

The behavior of the VRT parameter upon the application of variant 1 was different. The observed trend in changes in VRT after the test as compared with baseline was not as discernible as in the case of variant 2. After the application of variant 1, VRT decreased in 4 out of 10 participants involved in the study (this change related to both the lower limbs and was recorded after each of the three tests in each participant), while in the other 6 men VRT increased (this change also related to both the lower limbs and also was recorded after each of the three tests in each participant). Differences in VRT after variant 1 as compared with baseline were not statistically significant.

The study conducted by Bishara et al. [21] in a group of 25 physically active healthy participants demonstrated that the VRT measured after the use of photoplethysmography decreased in a statistically significant manner after a 5-h or longer daily activity in a standing posture. An abnormally short VRT (below 18 s) was recorded for 21% of participants, whose baseline VRTs at the beginning of the day were normal.

The results obtained in the group of 10 participants may indicate that in the study group of participants, 20-min standing in variant 2 resulted in more adverse changes within the venous system of the lower limbs than 20-min seating in variant 1.

Furthermore, in each participant, for each of the three tests within each variant, the same – increasing or decreasing – trend was observed with regard to the VRT parameter. This may lead to a suspicion that in a specific person, a certain body posture, e.g., a standing posture will have, in the long term, a more adverse impact on the venous system of the lower limbs than, e.g., prolonged sitting.

Furthermore, it is worthy of mention that even variants of the study with small loads applied to healthy young participants can induce adverse effects on the parameters describing peripheral circulation.

In conclusion, it appears that a re-observation of persons who took part in this study using the variants described would be useful. This would allow for the verification of the obtained results and possible confirmation of observed trends.

It also seems interesting to check how the VRT would change before and after the described variants of the study in other study groups, e.g., among young women, among elderly workers without CVI, etc. It appears that it would also be possible to increase the number of variants of the study (e.g., to introduce an additional variant: standing with a load).

The lower limbs should be regarded as a considerably autonomic body part, participating in the regulation of vascular and extravascular fluid volume including the venous return as well as the accumulation of several 'spare' litres of extravascular and extracellular to regulate the body fluid volume.

Disclosure statement

No potential conflict of interest was reported by the authors.

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