ARTÍCULO

Examination of vascular stiffness by photoplethysmography: features of daytime dynamics

Salus

Salus.2025; 29(3):26-30

Examen de la rigidez vascular mediante fotopletismografía: características de la dinámica diurna

Kira M. Trushina[1]

ABSTRACT

Introduction: Mortality from cardiovascular diseases is a serious medical problem worldwide. Many of the diagnostic methods currently used are applicable only in hospital settings (transesophageal electrocardiostimulation, echocardiography), and some have significant risks (myocardial scintigraphy, angiography). In this regard, the search and use of safe, informative and inexpensive diagnostic tools is very relevant. Monitoring of hemodynamic changes and blood volume parameters and, consequently, assessment of vascular aging by photoplethysmography can be an important addition to modern methods of heart and vascular research. **Objetive:** In this work, a combined study of the indicators of the vascular wall and blood pressure in daily dynamics was carried out. **Materials and Methods:** The measurements using AngioCode 101 were carried out in accordance with the requirements of operating the device in the morning and evening hours. the heart rate, age of the vascular system (in years), type of pulse curves (A, B or C), vascular stiffness (in %), stress index (in conventional units) and blood oxygen saturation (in %), were assessed. Significant differences in the results were assessed using the parametric paired Student's t-test and the nonparametric z-test of signs. The calculations were performed using Origin 7.0 software for Windows and an online statistics service (https://www.socscistatistics.com). **Results:** Possible explanations for the revealed changes are discussed.

Palabras clave: vascular stiffness, blood pressure, photoplethysmography, pulse wave.

[1.]Gymnasium #94, Kazan, Russia.

Autor de Correspondencia: Kira M. Trushina

e-mail: kiram.trushina@mail.ru

Recibido: 23/11/2025 **Aprobado**: 30/11/2025

RESUMEN

Introduccion: La mortalidad por enfermedades cardiovasculares es un grave problema médico en todo el mundo. Muchos de los métodos de diagnóstico que se utilizan actualmente solo son aplicables en entornos hospitalarios (electroestimulación transesofágica, ecocardiografía) y algunos conllevan riesgos importantes (gammagrafía miocárdica, angiografía). En este sentido, la búsqueda y el uso de herramientas de diagnóstico seguras, informativas y económicas, es muy relevante. La monitorización de los cambios hemodinámicos y los parámetros del volumen sanguíneo y, en consecuencia, la evaluación del envejecimiento vascular mediante fotopletismografía pueden ser un complemento importante para los métodos modernos de investigación cardíaca y vascular. **Objetivo:** En este estudio se llevó a cabo un estudio combinado de los indicadores de la pared vascular y la presión arterial en la dinámica diaria. **Materiales y métodos:** Las mediciones con AngioCode 101 se realizaron de acuerdo con los requisitos de funcionamiento del dispositivo por la mañana y por la noche. Se evaluaron la frecuencia cardíaca, la edad del sistema vascular (en años), el tipo de curva del pulso (A, B o C), la rigidez vascular (en %), el índice de estrés (en unidades convencionales) y la saturación de oxígeno en sangre (en %). Las diferencias significativas en los resultados se evaluaron mediante la prueba paramétrica t de Student para muestras emparejadas y la prueba no paramétrica z de signos. Los cálculos se realizaron utilizando el software Origin 7.0 para Windows y un servicio de estadísticas en línea (https://www.socscistatistics.com). **Resultados:** Se discuten las posibles explicaciones de los cambios revelados.

Key words: rigidez vascular, presión arterial, fotopletismografía, onda de pulso.

INTRODUCTION

By the end of 2025, the population of our planet is more than 8.23 billion people [1]. The top five countries with the largest population are India (1.46 billion), China (1.42 billion), the United States (about 347 million), Indonesia (285 million), Pakistan (255 million). Despite significant annual population growth, the death rate is also rising. Cardiovascular diseases (CVD) are one of the leading causes of death on the planet. According to the World Heart Observatory, about 20 million people die each year due to cardiovascular diseases.[2]

The mortality rate from CVD varies in different countries and for the Russian Federation is about 700 per 100 thousand population, in the USA it is about 2 times lower [3]. Due to the importance of the problem, the medical community uses various methods for diagnosing CVD, a large proportion of which are instrumental methods. Unfortunately, many of the diagnostic methods are applicable only in hospital settings (transesophageal electrocardiostimulation, echocardiography), and some have significant risks (myocardial scintigraphy, angiography). In this regard, the search and use of safe, informative and inexpensive diagnostic tools for CVD is very relevant. [4,5]

In the aspect of the above, devices based on the principle of photoplethysmography attract special attention as diagnostic tools. The main parameter changed by these devices is vascular stiffness, the increase of which (decrease in elasticity) underlies the development of many pathologies - arterial hypertension, coronary heart disease, arrhythmias, among others. [2,3]

Monitoring of hemodynamic changes and blood volume parameters and, consequently, assessment of vascular aging by photoplethysmography can be an important addition to modern methods of heart and vascular research.[6-8]

Currently, the assessment of the functional state of blood vessels, based on the method of photoplethysmography, is used in various clinical conditions. For example, in the Russian Federation, studies of vascular stiffness in hypertension[9-12] and atherosclerosis[13] have become particularly widespread.

However, this technique is also used in other cases: when assessing the state of the cardiovascular system during sports,[14,15] to assess cancer survival [16,17]. The relationship between the indicators of clinical and laboratory parameters of patients and the state of their vascular wall is often investigated, however, there is no data on the daily dynamics of these observations.[18]

This led to the relevance of this work, which carried out a combined study of the indicators of the vascular wall and blood pressure during the day.

MATERIALS AND METHODS

The study was conducted on an outpatient basis. The measurements using AngioCode 101 (ZMT Ltd, Russia) were carried out in accordance with the operating requirements of the device in the morning (about 9 a.m.) and evening (about 21 p. m.) hours.

The device assessed the heart rate, age of the vascular system (in years), type of pulse curves (A, B or C), vascular stiffness (in %), stress index (in conventional units), blood oxygen saturation (in %).

Arterial pressure (BP) was recorded according to a standard procedure using an automatic blood pressure monitor from A&D Medical (Japan), model UA-1100, immediately after using the AngioCode 101 device with the attached software (AngioCode version 3.40.01 developed by Scan Electronics, Russia). The data is presented as an average value ± standard deviation (SD) (Table 1).

Table 1. Arithmetic mean values (± standard deviation) of the studied parameters.

Parameter	Value
SBP-M	124,44262 ± 5,95406
SBP-E	124,7541 ± 5,64404
DBP-M	71,55738 ± 5,40532
DBP-E	73 ± 4,13521
HR-M-T	70,68852 ± 5,76062
HR-M-A	72,40984 ± 7,57491
HR-E-T	64,59016 ± 5,55391
HR-E-A	64,47541 ± 5,19489
AVS-M	39,37705 ± 3,28209
AVS-E	38,90164 ± 2,71849
VS-M	-6,84754 ± 3,13255
VS-E	-5,34754 ± 5,33715
SI-M	121,16393 ± 61,41096
SI-E	94,4918 ± 41,10256
S-M	97,96885 ± 0,47942
S-E	98,12333 ± 0,44811
A-M	8,18033 ± 19,19506
A-E	31,34426 ± 35,23061
B-M	29,7541 ± 29,73755
B-E	31,32787 ± 23,84584
C-M	62,06557 ± 37,4272
C-E	37,2459 ± 35,01031

Note: SBP-M — systolic blood pressure in the morning; SBP-E — systolic blood pressure in the evening; DBP-M — diastolic blood pressure in the morning; DBP-E — diastolic blood pressure in the evening; HR-M-T and HR-M-A — heart rate in the morning recorded by the tonometer (T) and with the Angiocode device (A), HR-E-T and HR-E-A – heart rate in the evening, recorded by the tonometer (T) and with the Angiocode device (A); AVS-M – the age of the vascular system in the morning, AVS-E – the age of the vascular system in the evening; VS-M – vascular stiffness in the morning, VS-E – vascular stiffness in the evening; SI-M – stress index in the morning, SI-E – stress index in the evening; S-M – saturation in the morning, S-E – saturation in the evening; A-M – pulse curve in the morning, A-E – pulse curve A in the evening; B-M – pulse curve in the morning, B-E – pulse curve in the evening; C-M – pulse curve in the morning, C-E – pulse curve in the evening.

To check whether our data correspond to a normal distribution, the Shapiro–Wilk criterion (Table 2) for normality was applied.

Significant differences in the results were assessed using the parametric paired Student's t-test and the nonparametric z-test of signs (Table 3).

The calculations were performed using Origin 7.0 software for Windows and an online statistics service.[19]**T**

Table 2. Values of the Shapiro–Wilk normality criterion for the studied parameters.

Parameter	Value	Normality
SBP-M	0,97196	Normal
SBP-E	0,97399	Normal
DBP-M	0,97999	Normal
DBP-E	0,96122	Normal
HR-M-T	0,98133	Normal
HR-M-A	0,96697	Normal
HR-E-T	0,95581	Normal
HR-E-A	0,95049	Normal
AVS-M	0,97164	Normal
AVS-E	0,93360	Normal
VS-M	0,97823	Normal
VS-E	0,97756	Normal
SI-M	0,88223	Not Normal at 0,05 level
SI-E	0,93784	Not Normal at 0,05 level
S-M	0,93036	Not Normal at 0,05 level
S-E	0,97384	Normal
A-M	0,49645	Not Normal at 0,05 level
A-E	0,79137	Not Normal at 0,05 level
B-M	0,82676	Not Normal at 0,05 level
B-E	0,92729	Not Normal at 0,05 level
C-M	0,81982	Not Normal at 0,05 level
C-E	0,84711	Not Normal at 0,05 level

Note: SBP-M — systolic blood pressure in the morning; SBP-E — systolic blood pressure in the evening; DBP-M — diastolic blood pressure in the morning; DBP-E — diastolic blood pressure in the evening; HR-M-T and HR-M-A — heart rate in the morning recorded by the tonometer (T) and with the Angiocode device (A), HR-E-T and HR-E-A – heart rate in the evening, recorded by the tonometer (T) and with the Angiocode device (A); AVS-M – the age of the vascular system in the morning, AVS-E – the age of the vascular system in the evening; VS-M – vascular stiffness in the morning, VS-E – vascular stiffness in the evening; SI-M – stress index in the morning, SI-E – stress index in the evening; S-M – saturation in the morning, S-E – saturation in the evening; A-M – pulse curve in the morning, A-E – pulse curve A in the evening; B-M – pulse curve in the morning, B-E – pulse curve in the evening; C-M – pulse curve in the morning, C-E – pulse curve in the evening.

Table 3. Values of parametric paired Student's t-test and the nonparametric z-test of signs for the studied parameters.

Comparison	Test Value	Significance
SBP: M vs E	t = 0,39489	NS
DBP: M vs E	t = 1,82577	NS
HR-M: T vs A	t = 2,63972	Significant
HR-E: T vs A	t = 0,19729	NS
HR-T: M vs E	t = 6,08225	Significant
HR-A: M vs E	t = 6,90708	Significant
AVS: M vs E	t = 0,921	NS
VS: M vs E	t = 2,09778	Significant
SI: M vs E	z = 2,4327	Significant
S: M vs E	z = 1,05045	NS
A: M vs E	z = 4,6188	Significant
B: M vs E	z = 0,13019	NS
C: M vs E	z = 3,31133	Significant

Note: SBP — systolic blood pressure; DBP — diastolic blood pressure; HR — heart rate recorded by the tonometer (T) and with the Angiocode device (A); AVS-M – the age of the vascular system in the morning, AVS – the age of the vascular system; VS – vascular stiffness; SI – stress index; S – saturation; A – pulse curve A; B – pulse curve B; C – pulse curve C. NS - the difference is not significant.

RESULTS AND DISCUSSION

For two months, in the morning and evening (n=61), parameters such as systolic and diastolic blood pressure, heart rate, age and stiffness of the vascular wall, stress index, blood oxygen saturation and types of pulse curves were measured (Table 1). An analysis of the recorded parameters of these indicators after statistical processing (both parametric and nonparametric statistical criteria were used, since not all data sets showed a normal distribution - see Table 2) allowed us to conclude the following.

The systolic pressure recorded in the morning did not differ significantly from that for the evening period (t=0.39489 at 0.05, the difference in the mean values of the general population does not differ significantly from the test difference). The same can be said about diastolic blood pressure (t=1.82577). The heart rate (HR) was recorded by two devices. If we compare the heart rate in the morning and evening recorded by both the tonometer and the Angiocode device, we can say that there was a statistically significant decrease in the values of this parameter in the evening (t=6.08225 and t=6.90708, respectively).

There were no significant differences in the age of the vascular system observed in the morning and evening (t=0.921), as well as in blood oxygen saturation (z=1.05045), and the vascular stiffness index was lower in the morning (t= 2.09778). The stress index, on the contrary, had significantly increased values in the morning (z=2.4327). Significant differences in pulse curves were noted for wave A (more than a threefold decrease in the morning, z=4.6188) and wave C (almost a twofold increase in the morning, z=3.31133), while no significant differences were noted in wave B (z=0.13019).

A decrease in heart rate before bedtime is consistent with a normal pattern of activity of the autonomic nervous system[20]. The decrease in vascular stiffness in the morning can probably be explained by the fact that the intake of dietary salt into the body stops at night, and the resumption of its consumption in the morning is reflected in a slight (slightly more than 20 %) increase in vascular stiffness in the evening. The dependence of vascular stiffness on salt intake has been demonstrated previously.[21]

A decrease in vascular stiffness in the morning was accompanied, as noted above, by a reduction in the duration of wave A and an increase in the proportion of wave C, which in itself has a positive correlation and indicates a better physiological state of the vascular endothelium in the morning. Increased stress index values in the morning may be related to the peculiarities of the circadian rhythm of cortisol synthesis -it is known that its maximum amount is synthesized in the morning [22]. In addition, the observed (10 %) slight (but statistically significant) increase in heart rate in the morning can also be clearly explained by the peculiarities of the circadian rhythm of cortisol.

Thus, the conducted research shows that medical devices based on the photoplethysmography method can make a significant contribution to the assessment of the state of key parameters of the cardiovascular system. The revealed differences in the daily dynamics of heart rate, vascular stiffness and, consequently, the characteristics of pulse waves direct the attention of researchers to the importance of taking measurements at least twice a day. For a more accurate analysis of the vascular endothelium, it is desirable to combine noninvasive instrumental photoplethysmographic examination with laboratory studies of a number of biochemical blood parameters (neutrophil elastase, P-selectin, endothelin-1, endogenous NO synthase inhibitor).[23]

REFERENCES

1.World Population Review. World Population Review [Internet]. [citado 2025 Marzo 23]. Disponible en: https://worldpopulationreview.com/

2.Lindstrom M, DeCleene N, Dorsey H. Global burden of cardiovascular diseases and risks collaboration, 1990-2021. J Am Coll Cardiol. 2022;80(25):2372–2425.

3.World Heart Federation. World Heart Observatory [Internet]. [citado 2025 Abril 03]. Disponible en: https://world-heart-federation.org/world-heart-observatory/

4. Xu X, Wang B, Ren C, Hu J, Greenberg DA, Chen T, Xie L, Jin, K. Age-related impairment of vascular structure and functions. *Aging Dis*. 2017;8:590-610.

5. Hellqvist H, Karlsson M, Hoffman J, Kahan T, Spaak J. Estimation of aortic stiffness by finger photoplethysmography using enhanced pulse wave analysis and machine learning. *Front Cardiovasc Med.* 2024;11:1350726. doi: 10.3389/fcvm.2024.1350726.

6. Hong J, Nandi M, Charlton PH, Alastruey J. Noninvasive hemodynamic indices of vascular aging: an in silico assessment. *Am J Physiol Heart Circ Physiol.* 2023;325(6):H1290-H1303. doi: 10.1152/ajpheart.00454.2023.

7. Karimpour P, May JM, Kyriacou PA. Photoplethysmography for the assessment of arterial stiffness. Sensors (Basel). 2023;23(24):9882. doi: 10.3390/s23249882.

8. Lin WH, Zheng D, Li G, Chen F. Age-related changes in blood volume pulse wave at fingers and ears. IEEE *J Biomed Health Inform.* 2023;28(9):5070-5080. doi: 10.1109/JBHI.2023.3282796.

9. Matviyevskaya EN, Kolbasnikov SV. Application of photoplethysmography in a comprehensive examination of patients with arterial hypertension and hyperuricemia in rural medical stations. *Tverskoy Medical Journal.* 2023;1:217-221.

10. Gorshunova NK, Korobanov Yu.Yu. Markers of vascular stiffness in aging and arterial hypertension. *Clinical Gerontology.* 2017;23(9-10):15-16.

11. Tuktarov AM, Filippov AE, Obrezan AA, Kukol LV. Possibilities of pulse wave contour analysis in the diagnosis of early vascular aging. *Rational pharmacotherapy in cardiology*. 2020;16 (3):356-362.

12. Shevchenko Yu. F, Gorelik SG, Il'nitsky AN, Bokova NA. Vascular wall stiffness and dyssarcopenia/sarcopenia in older women with arterial hypertension. Modern problems of health care and medical statistics. 2022;1:232-253.

13. Kobzeva ND. Features of endothelial dysfunction in patients with atherosclerotic lesions of various vascular beds. *Medical almanac.* 2022;1(70):29-36.

14. Shirokova AA, Balykova LA, Ivyansky SA, Krasnopolskaya AV, Samarin AV. Impaired elastic properties of the vascular wall as one of the mechanisms of increased blood pressure in children and adolescents involved in active sports. International Journal of Medicine and Psychology. 2023;6(3):51-59.

15. Govorukhina AA, Nezhinskaya Yu. A. Risk of developing cardiovascular disorders in 10-11-year-old girls involved in acrobatics in northern conditions. Bulletin of Surgut State University. 2017;4(18):8-13.

16. Andreeva OV, Semenov NN, Shchekochikhin D Yu, Novikova AI, Potemkina NA, Ozova MA, Kuli-Zade ZA, Levina VD, Shmeleva AA, Poltavskaya MG. Frequency of endothelial dysfunction and increased vascular stiffness in patients with solid malignant neoplasms. Almanac of Clinical Medicine. 2022;50(2):103-110.

17. Potemkina NA, Glezer MG, Zeynalova PA, Chomakhidze P. Sh, Novikova AI, Petrova GD, Poltavskaya MG. Structural and functional state of arteries in patients with hemoblastoses before and after high-dose chemotherapy and autologous hematopoietic stem cell transplantation. Almanac of Clinical Medicine. 2023;51(5):259-269.

18. Berulava KR, Levina EM. Features of endothelial function in critically ill patients with a therapeutic profile with different outcomes. Bulletin of the Russian Military Medical Academy. 2021;40(S1-3):47-52.

19. SocSciStatistics. Chi-Square Calculator [Internet]. [citado 2025 Marzo 28]. Disponible en: https://www.socscistatistics.com/tests/chisquare2/default2.aspx

20. Bolshev AS. Heart rate. Physiological and pedagogical aspects of the teaching aid / A.S. Bolshev, D.G. Sidorov, S.A. Ovchinnikov. Nizhny Novgorod State University of Architecture and Civil Engineering. University: – N.Novgorod: NNGASU, 2017. – 76 p. ISBN 978-5-528-00188-3

21. Baldo MP, Brant LCC, Cunha RS, Molina MDCB, Griep RH, Barreto SM, Lotufo PA, Bensenor IM, Mill JG. The association between salt intake and arterial stiffness is influenced by a sex-specific mediating effect through blood pressure in normotensive adults: The ELSA-Brasil study. *J Clin Hypertens (Greenwich).* 2019;21(12):1771-1779. doi: 10.1111/jch.13728.

22. Vlasenko N. Yu, Vlasenko MA. Features of the circadian rhythm of human cortisol during forced sleep deprivation. Bulletin of Irkutsk State University. Series: *Biology. Ecology.* 2019;30:105–115. https://doi.org/10.26516/2073-3372.2019.30.105.

23. Savicheva AA, Berns SA, Isaykina O. Yu, Gorshkov A. Yu, Veremeev AV, Drapkina OM. Paraclinical diagnostics of endothelial function reflecting vascular stiffness: the present and prospects. Literature review. *Cardiovascular Therapy and Prevention.* 2025;24(6):4426. doi: 10.15829/1728-8800-2025-4426.