DOI: 10.2478/pielxxiw-2023-0003

Arterial hypertension and pulse wave velocity

Nadciśnienie tętnicze i prędkość fali tętna

Gorazd Laznik[1], Matej Reisp[2]

[1]Faculty of Health Science, University of Novo mesto, Slovenia
[2]University Medical Centre Ljubljana, Slovenia

CORRESPONDING AUTHOR:
Gorazd Laznik
Faculty of Health Science, University of Novo mesto
Na Loko 2, 8000, Novo mesto, Slovenia
e-mail: gorazd.laznik@uni-nm.si

STRESZCZENIE

NADCIŚNIENIE TĘTNICZE I PRĘDKOŚĆ FALI TĘTNA

Cel pracy. Celem pracy jest identyfikacja związku między nadciśnieniem tętniczym a PWV u pacjentów z NT oraz ustalenie, czy NT jest czynnikiem ryzyka przyspieszającym rozwój miażdżycy.

Materiał i metody. Za pomocą ilościowej metody badawczej zbadaliśmy, wyjaśniliśmy i zdefiniowaliśmy wpływ nadciśnienia tętniczego na wskaźnik wzrostu PWV obserwowany w różnych grupach wiekowych pacjentów, którzy już mają nadciśnienie tętnicze. Wyodrębniono dane z dokumentacji medycznej pacjentów z systemu operacyjnego At Cor Sphygmocor.

Wyniki. Próba obejmowała 191 pacjentów z AH. Wartości PWV były prawidłowe u 72% pacjentów z optymalnym ciśnieniem krwi (BP), 60% pacjentów z prawidłowym ciśnieniem tętniczym miało podwyższone PWV przy wysokim prawidłowym BP, a AH stopnia 1 wynosiło 53% podwyższonego PWV, 53% prawidłowego PWV stopnia 2 Nadciśnienie tętnicze wzrosło u 94% w nadciśnieniu tętniczym 3. stopnia, a u 50% pacjentów stwierdzono podwyższone wartości PWV w izolowanym skurczowym nadciśnieniu tętniczym.

Wnioski. Wyniki badań niewątpliwie wskazują na znaczenie nadciśnienia tętniczego dla wzrostu prędkości fali tętna, z najsilniejszą korelacją w 3. stopniu nadciśnienia tętniczego oraz w grupach wiekowych od 30 do 49 lat. Średnio wartość PWV u pacjentów z nadciśnieniem wzrosła o 8%, co oznacza zwiększone ryzyko powikłań sercowo-naczyniowych.

Słowa kluczowe: **miażdżyca, nadciśnienie tętnicze, prędkość fali tętna**

ABSTRACT

ARTERIAL HYPERTENSION AND PULSE WAVE VELOCITY

Aim. The purpose of the study is to identify the connection between high blood pressure and PWV in patients with AH and determine if AH is a risk factor that accelerates the development of atherosclerosis.

Material and methods. With quantitative research method we investigated, explained, and defined the effects of arterial hypertension with the PWV increase-rate observed across different age groups of patients who already have AH. Data from patients' medical records from the At Cor Sphygmocor operating system were extracted.

Results. The sample included 191 patients with AH. PWV values were normal in 72% of patients with optimal blood pressure (BP), 60% of patients with normal BP had increased PWV in high normal BP and grade 1 AH were 53% of increased PWV, 53% of normal PWV in grade 2 AH, increased in 94% in grade 3 AH, and 50% of patients had increased PWV values in isolated systolic AH.

Conclusions. The research results undoubtedly show the importance of arterial hypertension for the increase in pulse wave velocity, with the clearest correlation at grade 3 AH and in the age groups between 30 and 49 years. On average, the PWV value in hypertensive patients rose by 8%, which represents an increased risk of cardiovascular complications.

Key words: **atherosclerosis, arterial hypertension, pulse wave velocity**

INTRODUCTION

Arterial hypertension (AH) is a chronic non-communicable disease that harms the human body. It causes cardiovascular complications, which are the leading cause of death worldwide with more than 10 million deaths per year. Cardiovascular complications, such as stroke and heart attack, are the leading cause of death in Slovenia at 40% [1]. The prevalence of hypertension is 24% in the adult male population and 20% in the adult female population, which is considered globally and in Europe as well. AH is also called a silent killer because it often causes no symptoms [2]. The untreated AH causes complications such as heart and kidney failure, hypertension retinopathy and atherosclerosis [3]. Patients with high blood pressure have a higher risk to get other chronic disease such as diabetes mellitus type 2, dyslipidaemia and dementia [1]. To confirm arterial hypertension, we need to meet two conditions. First is that the systolic blood pressure (BP) is ≥ 140 mmHg and diastolic ≥ 90. BP must be taken in ambulatory with proper methods and in the right way. The second is that the benefit of treatment of AH is higher than the risk of high BP. Based on research and evidence, AH is defined into seven categories. These categories are represented in the ESH (European Society of Hypertension) and ESC (European Society of Cardiology). Guidelines from 2013 are still valid and apply to the adult population [3] (Tab. 1).

Tab. 1. Category of ambulatory measured Bp

Category	Systolic BP (mmHg)		Diastolic BP (mmHg)
optimal BP	<120	or	<80
normal BP	120-129	or/and	80-84
high normal BP	130-139	or/and	85-89
grade 1 AH	140-159	or/and	90-99
grade 2 AH	160-179	or/and	100-109
grade 3 AH	≥180	or/and	≥110
Isolated systolic hypertension	≥140	or	≤90

Atherosclerosis is a chronic degenerative disease that affects the inner walls of the arteries. When the inner wall of the artery is damaged due to mechanical, chemical or metabolic causes, inflammation responses with the formation of a plaque [4]. Atherosclerosis leaves consequences in the arteries over a long period, arteries become stiffer and damaged. The development of atherosclerosis is conditioned by age, risk factor, chronic diseases and an unhealthy lifestyle [5].

Due to the effect of atherosclerosis in patients with high cardiovascular risk, diagnostic tests should be performed to discover and prevent atherosclerosis development. One of the methods is PWV measurement. PWV is a non-invasive and painless diagnostic test that shows us the speed of pulse waves which run through the aorta and it is strongly correlated to atherosclerosis [6]. PWV measurement is suitable for different types of outpatient clinics such as cardiology, nephrology and angiology. To describe PWV, we need to understand the physiology of pulse wave.

Blood flow is a dynamic process. The pulse wave begins when the left ventricle ejects blood into the aorta from the point of the heart, which then travels along the aorta. When the pulse wave comes to aortic bifurcation and smaller arteries, the pulse wave bounces off and travels in the opposite direction towards the heart. At the same time, the speed of the pulse and the strength of the reflected wave depend on the stiffness of the aorta and arteries, the distance travelled, the heart rate, the ejection fraction of the left ventricle and the pulse volume. The stiffer walls of the artery and aorta cause a higher pulse wave speed and vice versa, when the artery is flexible, the speed will be lower [7]. Atherosclerosis can be directly linked to increased stiffness and faster blood flows through large arteries [8].

To determine the pulse wave speed, we can use the carotid-femoral PWV (cfPWV) measurement, which is considered the golden standard among other methods. PWV measurement is also recommended by the guidelines for AH to evaluate stiffness of the aorta. PWV is important as a biomarker which is correlated to cardiovascular risk. If PWV is >10 m/s, it represents a change in the aortic function [9]. PWV reference values were established in a multi-European study in 2010, collecting data from 16,867 individuals (table 2). Criteria were set for healthy individuals and individuals with increased cardiovascular risk [10]. These values are still valid according to the latest ESH/ESC guidelines. Slovenian Guidelines for the Treatment of Hypertension from 2018 also recommended PWV for determining cardiovascular risk in a patient with AH [11].

Tab. 2. Values of the PWV dependent on age and BP

Age	BP category				
	Optimal	Normal	High normal	Grade 1 AH	Grade 2 and 3 AH
	Pulse wave velocity m/s (±2 SD)				
<30	6.1 (4.6-7.5)	6.6 (4.9-8.2)	6.8 (5.1-8.5)	7.4 (4.6-10.1)	7.7 (4.4-11.0)
30-39	6.6 (4.4-8.9)	6.8 (4.2-9.4)	7.1 (4.5-9.7)	7.3 (4.0-10.7)	8.2 (3.3-13.0)
40–49	7.0 (4.5-9.6)	7.5 (5.1-10.0)	7.9 (5.2-10.7)	8.6 (5.1-12.0)	9.8 (3.8-15.7)
50–59	7.6 (4.8-10.5)	8.4 (5.1-11.7)	8.8 (4.8-12.8)	9.6 (4.9-14.3)	10.5 (4.1-16.8)
60–69	9.1 (5.2-12.9)	9.7 (5.7-13.6)	10.3 (5.5-15.1)	11.1 (6.1-16.2)	12.2 (5.7-18.6)
≥70	10.4 (5.2-15.6)	11.7 (6.0-17.5)	11.8 (5.7-17.9)	12.9 (6.9-18.9)	14.0 (7.4-20.6)

AIM

The purpose of the study is to identify the correlation between high blood pressure and PWV in patients with AH and determine if AH is a risk factor that accelerates the development of atherosclerosis. This is highly important for nurses because in Slovenia PWV measurements are mainly in the domain of nurses. Our effort in a study is to explain the PWV importance because it is a strong

predictive marker for cardiovascular risk. With understanding of the PWV, a nurse can make great medical education work which can be highly motivating for patients. Therefore, we have asked ourselves »How is arterial hypertension associated with atherosclerosis? « and »What is the link between arterial hypertension and increased pulse wave speed? «

MATERIALS AND METHODS

In the study, we used the quantitative method of research by collecting data on the PWV and BP measurements. Based on the literature examined, we made a template for the analysis of statistical data, according to which, we processed data on PWV measurements and blood pressure values. The analysis template consists of six templates that we had to reply and define the link between PWV and AH.

BP measurements were performed in the hypertension clinic using a validated Omron blood pressure device. The measurements were carried out according to the protocol described in the Slovenian Guidelines for the Treatment of Hypertension 2018. All BP measurements were taken in ambulatory after 5 minutes rest in a sitting position on the hand with higher BP. We have taken 3 measurements with 30 seconds pause between each measurement. We use average BP. The carotid-femoral method with applanation tonometry was used for PWV measurements. We used the Sphygmocor device (At Cor Medical, Sydney, Australia) the tonometry-based technique. PWV was calculated between two recording points and the heart. The first point was the distance between the carotid artery and the suprasternal notch. The second point was on the femoral artery which was the distance between the suprasternal notch and the femoral artery. With this method, we calculated the difference in transit time of the pulse wave between each point and the heart (ECG) divided by the travel distance. Measurements were taken in lying position after 5 minutes rest. Both measurements were taken by the same patients.

For the study, we obtained data from 191 patients. The sample was 50.3% (96) male and 49.7% (95) female. When it comes to 7.9% (15) of patients, they were in the age group up to 30 years, 25.8% (49) in the age group of 30-39 years, 13.2% (25) in the age group from 40 to 49, 15.8% (30) patients in the 50-59 age group, 22.6% (43) of patients in the 50-59 age group and 14.7% (28) of patients in the age group from 60-69. The average age of patients was 53 years.

The data was obtained from the At Cor Syphigmocor information system from the specialist hypertension clinic called "Bolnica dr. Petra Držaja". The parameters used in the study were gender, age, systolic and diastolic blood pressure and PWV. The stage of data collection and processing, considered all ethical principles of scientific research work and the anonymity of the data processed was ensured.

The study was approved by ethical committee of University of Novo mesto, Faculty of Health Science (FZV-77/2020).

RESULTS

Below we present the part of the study [12], which is important for the interpretation of this paper and the subsequent answer to research questions.

Figure 1. shows the PWV values according to BP for the total sample and the proportion of patients in each BP category. The number of 11 patients (5.8%) had normal BP, 15 patients (7.9%) had optimal BP and 19 patients (9.9%) had high normal BP. Grade 1 hypertension had 14 patients (7.3%), grade 2 hypertension 21 patients (11%), grade 3 hypertension 17 patients (8.9%), and 94 patients had isolated systolic hypertension (49.2%).

Patients with optimal BP had 72% (8) normal PWV values. In normal BP, higher PWV values prevailed with 60% (9). In high normal KT and grade 1 hypertension, higher PWV values with 53% (10) were slightly ahead of normal PWV. In grade 2 hypertension, normal PWV values prevailed at 53% (11). In grade 3 hypertension, higher PWV levels are at a significant advantage of 94% (16). In isolated systolic hypertension, normal and higher PWV levels are uniform. On average, 55.5% (107) PWV were higher values.

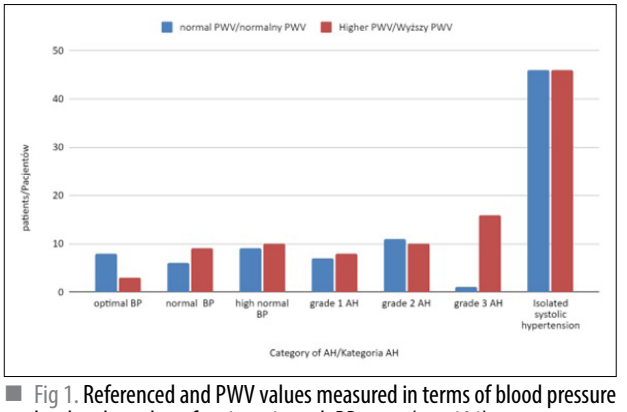

Fig 1. Referenced and PWV values measured in terms of blood pressure level and number of patients in each BP stage (n = 191)

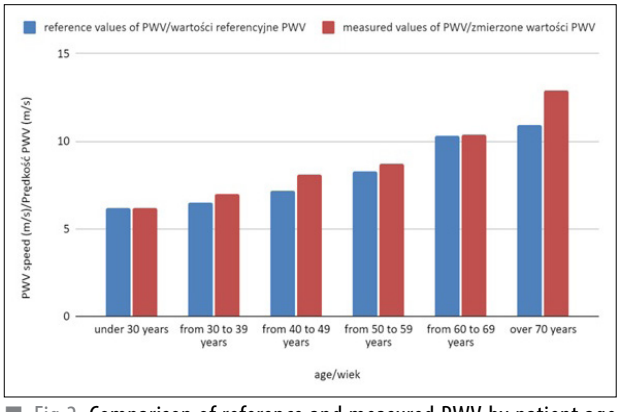

Fig 2. Comparison of reference and measured PWV by patient age (n = 191)

Figure 2. presents the PWV measurements that were compared with the reference values previously described in Table 2. (Values of the PWV dependent on age and BP). References values represent the PWV values of healthy individuals while our measured PWV values are for hypertonic patients. There are no deviations in the age group below 30

years. In the 30-39 age group, the PWV speed increased by 0.5 m/s. In the 40-49 age group, PWV was increased by 0.9 m/s. In the 50-59 age group, PWV was increased by 0.4 m/s. In the 60-70 age group, PWV was increased by 0.1 m/s and in the age group over 70 by 2 m/s.

In the third figure, we show the measured PWV values, which were grouped by age group and placed in normal and higher PWV values. In the age group up to 30 years, normal PWV values are prevalent at 60%. In the 30-39 age group, higher PWV values are prevalent with 64%. In the 40-49 age group, the highest increase in PWV values is recorded at 76%. In the 50-59 age group, a slight advantage of normal PWV values of 51% is recorded. In the 60-69 age group, normal PWV values are dominated by 53%. In the age group of 70 years and above, normal PWV values prevail at 57%.

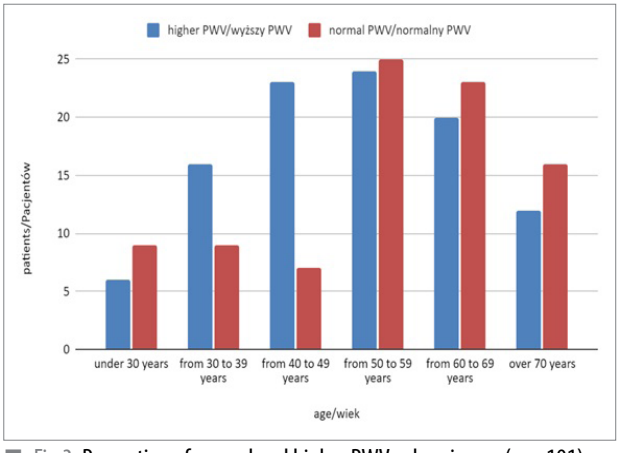

Fig 3. Proportion of normal and higher PWV values in age (n = 191)

DISCUSSION

Atherosclerosis is increasingly expressed with age, as it is a chronic degenerative process in the arteries. With age, the presence of atherosclerosis is expected and is normal to some extent. This can be seen in Table 2, where PWV values range between 6 and 7 m/s in younger people and in the elderly at about 10 m/s. From these PWV results, we conclude that the arteries of elder people are stiffer than the arteries of the younger ones , even though they do not have risk factors such as AH [10]. Therefore, we also expected that the higher PWV values in the elderly would be less noticeable, as atherosclerosis is already expressed and expected. This is due to data from Graph 3, where it can be seen that values with normal PWV prevailed at a higher age.

Higher BP increases the chance of developing atherosclerosis by 25% and is an important factor in the development of cardiovascular complications [2]. A Norwegian study [13], which looked at the impact of genetics and increased blood fats on the formation of atherosclerosis in women, found that only a small percentage of women (5.7% of the nearly 28,000 women) aged between 25 and 40 had suffered from a cardiovascular event. The impact of PWV was also shown in the J-HOP study, where they found the link between home BP measurements, PWV and cardiovascular events. They found that patients with higher PWV and high home BP has a greater risk for cardiovascular events [14]. In our sample, the most noticeable effect of BP on the development of atherosclerosis is observed in the 30-49 age groups. In fact, the 3rd graph shows that over 70% of patients had elevated PWV levels in the 30-49 age groups. For the overall sample, 76% of patients had elevated BP levels. It can be inferred that even in the 30-49 age groups, the majority of patients had elevated BP. The fact is that the importance of AH in the formation of atherosclerosis in the age group from 30 to 49 years is high. This is also due to increased PWV speeds, which are by 0.5 m/s higher in the 30-39 age group and by 0.9 m/s higher in the 40-49 age group.

At the age of 50, the proportion of patients with increased PWV values is lower. The atherosclerosis changes are already present at this age and higher PWV values, which are still normal for older patients were also obtained. Elder patients with hypertension and increased cardiovascular risk in many cases are treated with medicines that effect on arteries and cardiovascular system. This treatment aims to regulate risk factors such as hypertension, dyslipidaemia, and atherosclerosis. Because of that, we could get lower values of PWV as were suspected in elder persons [2]. Our claims about the treatment of AH are also detailed in the SPARTE study, where the important role of drugs for treatment of AH is identified.

Although they had hypertension with medium to very high risk [8], patients who take medicines for AH, had minimal increases in PWV (0.06 m/s/y) over a period of 4 years.

In response to the question »How is arterial hypertension associated with atherosclerosis?«, we can conclude according to our sample that in younger patients in the age group below 30 years, despite already being treated with AH the value of normal PWV is a strong advantage (Graph 1). The reasons can be found in the very process of developing atherosclerosis, which is slow at a younger age and more difficult to express in terms of higher PWV values.

High BP effects to the change in distribution of elastic fibbers and collagen fibbers in the arterial walls in the direction of the higher stiffness of the artery. This can already be seen in short-term changes and even better with the long-term changes which can be seen in PWV compared by age [1].

Meanwhile, patients with hypertension in the 30-49 age groups had both; the highest BP values and the most noticeable and higher PWV values. Our second conclusion is that arterial hypertension in our patients has had a significant impact on the development of atherosclerosis, especially in the largest age groups between 30 and 49 years.

The best way to answer the research question »What is the link between arterial hypertension and increased pulse wave velocity?« is by reviewing Graph 1, where we see a very high proportion of higher PWV values in grade 3 hypertension. At this grade, patients had more than 180 mmHg over 110 mmHg when measuring BP in the clinic. Usually, at such blood pressure, we talk about malignant hypertension, which is difficult to treat, and as a result, patients have severe damage to the target organs and ischemic vascular damage. The prognosis for untreated

malignant hypertension is poor, and mortality increases significantly [15].

Compared to groups with optimal and normal BP, there is an unexpected increase in PWV. In the group with optimal BP, we have a minimum rate of higher PWV values. Against expectations, patients with normal BP have a higher rate of increased PWV. Since we do not know how long patients have got higher BP before treatment, we can guess that this is one reason for higher PWV despite normal BP values in the clinic. Probably the second reason for higher PWV is an unhealthy lifestyle and other risk factors [16]. The results of the UK study show that increased artery stiffness occurs in 25.8% of the 22.452 healthy persons who do not have high blood pressure. The reason for increased artery stiffness are independent risk factors [17].

In our study, 76% of patients had high BP. In Graph 2., where reference and elevated PWV values are compared by age group, the average rate of PWV increased by 0.65 m/s. The largest increase was in the 40-49 age group (0.9 m/s) and over 70 years (2 m/s). Various studies have confirmed that an increase in PWV of 1 m/s is responsible for a 14 % higher risk of cardiovascular complications and a 15% higher risk of mortality [7].

The PWV values in our study are increased because of the effect of high BP, so we can confirm and answer the 2nd research question. AH has effects on increased PWV values which gain the risk of cardiovascular complications. However, these findings are also described in articles [17] [14] [6].

CONCLUSIONS

According to the results, we confirmed the relationship between AH and PWV, indicating accelerated development of atherosclerosis in hypertonic patients. With a simple and effective diagnostic test of PWV measurements, we obtained important data showing the patient's risk of cardiovascular risk. In particular, the effect of BP on atherosclerosis at the age of 30 to 49 years can be highlighted, as PWV is increased by almost 1 m/s. These are patients at risk of cardiovascular disease due to high PWV, AH, unhealthy lifestyle, and other risk factors. In the literature, PWV is interpreted as vascular age outcome, which means that the age of the blood vessels is assessed by measuring PWV according to the age of the subject. For example, if a 35-year-old person has PWV 10 m/s, it can be claimed that his arteries are comparable to the arteries of a person aged 70. These understandable but effective results of PWV can be used in medical education work which can also be performed by a nurse.

The fact that the incidence of AH is just nearly 25% can be concluded that one in four adult individuals in Slovenia and worldwide has AH. A nurse is gradually confronted with chronic patients, including hypertonic. A nurse must have the expert knowledge when dealing with chronic patients. The knowledge of PWV can help a nurse to motivate and direct patients toward a healthy lifestyle in order to prevent and handle the chronic disease.

In Slovenia, PWV measurements could be used on a larger scale, at all levels of the health system, namely at the primary level as the assessment of cardiovascular risk in hypertonic, diabetic, and cardiac patients. The measurement of PWV using the carotid-femoral method is the most reliable, but not most practical because it requires additionally qualified personnel. Using more accessible and simpler PWV devices that appear on the market allows wider use of PWV measurements and easier handling of the PWV device while suitable for screening. PWV measurements are useful at independent nurse work. In Slovenia, we have a reference clinic where nurses deal with stable chronic patients to prevent exacerbation of the chronic disease. Particularly in those reference clinics, we recommend PWV measurements based on our study outcomes.

Acknowledgements

We are grateful to all participants who made this study possible.

ORCID

Gorazd Laznik https://orcid.org/0000-0003-3281-1150

REFERENCES

1. Božič N, Knez J, Dolenc P, et al. Mesec meritev maj 2019. [in:] Dolenc P, ed. XXVIII. Strokovni sestanek združenja za arterijsko hipertenzijo. Ljubljana: Združenje za arterijsko hipertenzijo. Slovensko zdravniško društvo; 2019, s. 105-108.
2. Accetto R, Salobir B, BrguljanHitij J, et al. Slovenske smernice za obravnavo hipertenzije. Zdravniški vestnik. 2014; 83 (11): 727-758.
3. Dolenc P, Vujanić, A. Definicija arterijske hipertenzije. [in:] Dolenc P ed. XXVII. Strokovni sestanek združenja za arterijsko hipertenzijo. Ljubljana: Združenje za arterijsko hipertenzijo, Slovensko zdravniško društvo; 2018, s. 15-24.
4. Yuhua Z, Xuemei X, Zhenzhen W, et al. Research progress on the relationship between atherosclerosis and inflammation. Biomolecules. 2018; 8(3): 1-11.
5. Ježovnik M, Poredoš P. Vnetje – skupni patogenetski dejavnik arterijske aterosklerotične in venske trombembolične bolezni. Zdravniški vestnik. 2017; 86(5/6): 244-254.
6. Vallée A. Arterial Stiffness Determinants for Primary Cardiovascular Prevention among Healty participants. Journal of Clinical Medicine. 2022; 11(9): 2512: 1-11.
7. Turk M, Lunder M, Janić M, at al. Pomen hitrostipulzneg avala in centralnega arterijskega tlaka v klinični praksi. Medicinski razgledi. 2014; 53(2): 171-180.
8. Laurent S, Chatellier G, Azizi M, et al. SPARTE Study: Normalization of arterial stiffness and cardiovascular events in patients with hypertension at medium to very high risk. Hypertension. 2021; 78(4): 983-995.
9. Čegovnik B, Salobir B, Salobir N. Interpretacija izvidov za oceno s hipertenzijo povzročene prizadetosti organov. [in:] Dolenc P, ed. XXVIII. Strokovni sestanek združenja za arterijsko hipertenzijo. Ljubljana: Združenje za arterijsko hipertenzijo. Slovensko zdravniško društvo; 2019, s. 23-32.
10. Brunner-La Rocca HP. Towards applicability of measures of arterial stiffness in clinical routine. European heart journal. 2010; 31(19): 2320-2322.
11. Brguljan Hitij J, Dolenc P, Erhartič A, et al. Slovenske smernice za obravnavo hipertenzije, 2018, skrajšana verzija. [in:] Brguljan Hitij J, Dolenc P, Erhartič A, ed. Ljubljana: Združenje za arterijsko hipertenzijo. Slovensko zdravniško društvo; 2019.
12. Reisp M, Laznik G. Vpliv arterijske hipertenzije na poras thitrosti pulznega vala. [in:] Berkopec M ed. Izzivi integrirane zdravstvene in socialne oskrbe v času epidemije: Novo mesto. Društvo medicinskih sester, babic in zdravstvenih tehnikov Splošna bolnišnica Novo mesto Univerza v Novem mestu, Fakulteta za zdravstvene vede; 2022, s. 14-15.
13. Balder JW, Rimbert A, Zhang X, et al. Genetics, Lifestyle, and low-Density Lipoprotein Cholesterol in Young and Apparently Healthy Women. Circulation. 2018; 137(8): 820-831.
14. Ishiyama Y, Hoshide S, Kanegae H, et al. Impact of home blood pressure variability on cardiovascular outcome in patients with arterial stiffness: Results of the J-HOP study. The journal of clinical hypertension. 2021; 23(8): 1529-1537.

15. Božič N, Brguljan Hitij J. Register bolnikov z malign hipertenzijo. [in:] Dolenc P, ed. XXV. Strokovni sestanek združenja za arterijsko hipertenzijo. Ljubljana: Združenje za arterijsko hipertenzijo.Slovensko zdravniško društvo; 2016, s. 33-37.
16. Cevc M. Hipertenzija in hiperlipidemija. [in:] Dolenc P, ed. XXV. Strokovn isestanek Združenja za arterijsko hipertenzijo. Združenje za arterijsko hipertenzijo. Slovensko zdravniško društvo; 2016, s. 63-72.
17. Boutouyre P, Chowienczyk P, Humphrey JD, et al. arterial stiffness and cardiovascular risk in hypertension. Circulation research. 2021; 128(7): 864-886.

Manuscript received: 30.08.2022
Manuscript accepted: 14.11.2022