The Effect of Noise on Blood Flow Velocity in the Aorta

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Abstract **– The aim of the paper was to examine the effect of noise on the blood flow velocity through a period of three years on workers who work on press machine. It was proven that continuous exposure to noise affects the blood flow velocity through the aorta and increases the diameter of ascending aorta and this, consequently, leads to an increase in cardiovascular risk. Prevention of changes in the cardiovascular system is considered to be imperative, and the limitation of noise levels and the length of exposure to noise must be established as factors that must be planned during the construction of the work environment.**

Keywords **– aorta, blood flow velocity, noise pollution, computer methods and simulations**

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1. Introduction

Noise (unwanted sound) presents and etiological factor which is related to the risk of cardiovascular diseases [1], [2]. A sound of 85 dB is not a safe sound, and continuous exposure to such noise can lead to hearing loss [1], [2]. Continuous exposure to noise also leads to arterial hypertension, an increase in systolic and diastolic blood pressure, along with increase in heart rate and to remodeling of blood walls (leading to an expansion of blood vessels, that has effect on status of stable or unstable plaque, and an increase in cardiovascular risk itself) and has effect on the process of atherosclerosis itself [2], [3], [4], [5]. Exposure to noise increases the risk of developing ischemic heart disease, chronic coronary syndrome, acute myocardial infarction and stroke [6]. Noise has effect on the oxidative stress, so it can be considered as etiological factor of the formation of inflammatory processes, which is found in the background of numerous cardiovascular pathologies [7]. Blood flow is called a quantity of blood that passes through a certain point of the circulation system at a certain time [8], [9], [10]. Cross sectional area of the aorta is 2.5 cm2 [8], [9]. Aorta is the largest and the most important blood vessel in the body that allows the delivery of oxygenated tissue to the tissues and organs [10]. It leaves the left ventricle where it has a diameter of about 3 cm, after that there is an ascending part with about 5 cm in diameter, then it makes an arch to the back and left through the hilum of the left lung [10]. It is topographically divided into ascending, aortic arch and descending aorta [10]. Infrarenal aorta and its branches vascularize the large anatomical area, abdominal and pelvic wall, descendent colon and pelvic organs, reproductive organs and lower extremities [10].

Aneurisms represent a widening of aorta and etiologically are classified into congenital, aneurysms caused by connective tissue disorder, degenerative, infectious factors and can be poststenotic [10], [11]. The rate of blood flow in the aorta is measured by ultrasound, using Collor Doppler effect. A blood pressure gradient has an impact on blood flow through the blood vessel system. Increased peripheral resistance, arterial hypertension, tachycardia, hematocrit values, are conditions that affect changes in blood viscosity, blood vessel diameter, pathology, heart muscle state, and the appearance of cardiac valvular defects and can make differences in the rate of the flow through the aorta [9], [11]. Transmural pressure does not have a major effect on the aorta, and it is important for the flow rate through the lesser blood vessels [10]. The aortic flow is regulated by the heart rate of the heart itself, the flow rate affects the morphology of the aortic wall, and the occurrence of turbulent blood flow presents a risk for a cardiovascular accident [9]. Disturbance in blood flow has an effect on physiological parameters and processes, pressure, wall shear stress, remodeling and inflammation [12].

2. Aim

The aim of the article was to examine the effect of noise on the blood flow velocity through the infrarenal aorta on people who work on press machines through a period of three years. Also, the aim was to show the effect of noise on the diameter of the ascending aorta.

3. Methods

Research is prospective analysis which included 30 subjects who were in follow up for a period of three years (36 months). They worked on press machine for seven hours daily in the factory „CIMOS“, Zenica, Bosnia and Herzegovina. Through isohypes, the noise between 65 and 110 dB, spreads around ten press machines. At the same time, three workers worked on each press machine. Criteria for inclusion were as follows: obtained inform consent for participation in the study, no cardiovascular disease in anamnestic data, echocardiographically smooth blood flow over the aorta, and echocardiographic regular aortic valve function. Exclusion criteria were as follows: diagnosis of arterial hypertension, use of antihypertensive drugs, episodes of tachycardia, aortic valvular defect, root of aorta bigger than 4 cm. During a period of three years, none of the patients were taking any antihypertensive drugs. Aortic flow velocity was measured by ultrasound in the early morning hours, in the infrarenal segment of aorta by Collor Doppler (patient was in a supine position). For the evaluation of the abdominal aorta convex low-frequency transducers are used with a frequency range of 2.5–5 MHz, depending on the patient's body volume. Ultrasound is useful to demonstrate atherosclerotic changes of the aortic wall and to measure aortic diameter. The study was conducted in accordance with the basic principles of the Helsinki Declaration (last revision of 2008) on the rights of patients involved in biomedical research. The identity and all personal data of the patients were permanently protected in accordance with the regulations for the protection of identification data. For the purpose of protecting personal data, each patient was assigned an identification number. Regression analysis was used for statistical analysis, with MATLAB software (version 9.4, MathWorks, Natick, Massachusetts, United States of America) and Microsoft Excel (version 11 Microsoft Corporation, Redmond, Washington, USA). By entering the average flow velocity values in 30 subjects, the polynomial regression analysis of the third order enabled the flow rate prediction at any time during follow-up period which may be of importance in the everyday work with the same or similar machines that produce noise during their work (Figure 1.).

4. Results

Respondents were divided in relation to their position of work. Position 1 included 10 respondents, position 2 10 respondents, position 3 also 10 respondents. The mean blood flow velocities of the aortic blood are presented in Table 1. In order to estimate and predict the shape of response values (dependent variable) over a range of input parameter values (independent variable) we use a polynomial regression analysis of the third order (cubic curve), given by Equation 1.

$$y = b_0 + b_1 x + b_2 x^2 + b_3 x^3 \quad \text{(Eq. 1)}$$

where y_i is predicted outcome value for the polynomial model, with regression coefficients b0 ... b3 to be determined (Figure 1.). Although it will be simpler to use a quadratic polynomial, a use of a cubic curve is optimal in this case as it gives low bias and low invariance without unwanted noise (over-fitting).

If the number of measured values n >= 4 as it is in our case (n = 7), then (1) can be written as

$$\begin{aligned} b_0 + b_1{*}x_1 + b_2{*}(x_1)^2 + b_3{*}(x_1)^3 &= y_1 \\ b_0 + b_1{*}x_2 + b_2{*}(x_2)^2 + b_3{*}(x_2)^3 &= y_2 \\ b_0 + b_1{*}x_3 + b_2{*}(x_3)^2 + b_3{*}(x_3)^3 &= y_3 \quad \text{(Eq. 2)} \\ \vdots \quad\quad \vdots \quad\quad \vdots \quad\quad \vdots \\ b_0 + b_1{*}x_n + b_2{*}(x_n)^2 + b_3{*}(x_n)^3 &= y_n \end{aligned}$$

or in matrix form

$$\mathbf{A} * \mathbf{x} = \mathbf{b} \quad \text{(Eq. 3)}$$

where

$$\mathbf{A} = \begin{bmatrix} 1 & x_1 & (x_1)^2 & (x_1)^3 \\ 1 & x_2 & (x_2)^2 & (x_2)^3 \\ 1 & x_3 & (x_3)^2 & (x_3)^3 \\ : & : & : & : \\ 1 & x_n & (x_n)^2 & (x_n)^3 \end{bmatrix},$$

$$\mathbf{x} = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \dots \\ y_n \end{bmatrix}$$

In case the above system has a rank of 4 (at least 4 linearly independent rows), then the resulting system of normalized equations

$$\mathbf{A}^T \mathbf{A} \mathbf{X} = \mathbf{A}^T \mathbf{b} \quad \text{(Eq. 4)}$$

can be solved for unknown regression coefficients b_i, $i = 1,2...n$. In Equation 4, $\mathbf{A}^T$ is the transpose of matrix **A**, which implies that $\mathbf{A}^T \mathbf{A}$ is a square 4 x 4 matrix, so the system can be solved.

Although system of equations (4) can be solved analytically, in practice we usually apply numerical (approximative) methods, or use an alternative formulation based on matrix decompositions such as the QR or Singular Value Decomposition.

In addition, we can also calculate the coefficient of determination R^2, which is a statistical measure of how close the data are to the fitted regression line. Mathematically, it represents the percentage of the response variable variation that is explained by a regression model, and its value can be between 0 and 1 (0% and 100%). In general, the higher the R-squared, the better the model fits the data. In case of $R^2 = 1$, the model explains all the variability of the response data around its mean.

Table 1. Average blood flow velocity measured according to position on press machine

Work place (position)	Month 0 (cm/s)	After 6 months (cm/s)	After 12 months (cm/s)	After 18 months (cm/s)	After 24 months (cm/s)	After 30 months (cm/s)	After 36 months (cm/s)
1 (n=10)	42	44	45	52	57	61	65
2 (n=10)	41	44	47	53	59	60	61
3 (n=10)	43	43	45	51	56	62	69
Average	41,3	43,7	45	52	57,3	61	65

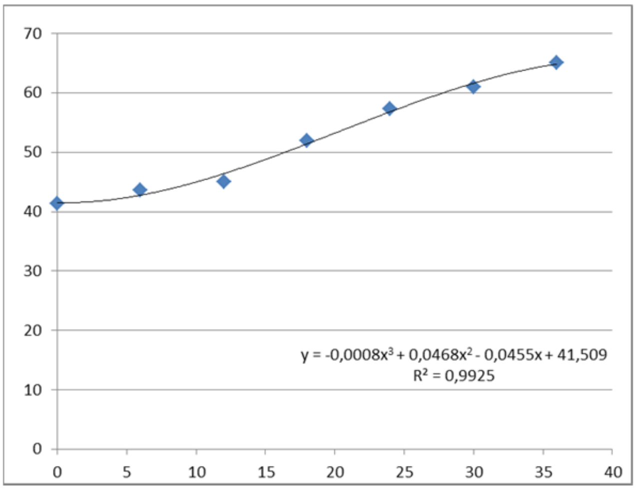

Figure 1. Average blood flow velocity estimation using a third-order polynomial regression analysis

Table 2. Aortic enlargement measured according to position on press machine

Work place (position)	Month 0 (cm)	After 6 months (cm)	After 12 months (cm)	After 18 months (cm)	After 24 months (cm)	After 30 months (cm)	After 36 months (cm)
1 (n=10)	2,52	2,54	2,55	2,59	2,63	2,66	2,70
2 (n=10)	2,50	2,53	2,55	2,58	2,61	2,65	2,68
3 (n=10)	2,50	2,52	2,54	2,57	2,62	2,65	2,67
Average	2,51	2,53	2,55	2,58	2,62	2,65	2,68

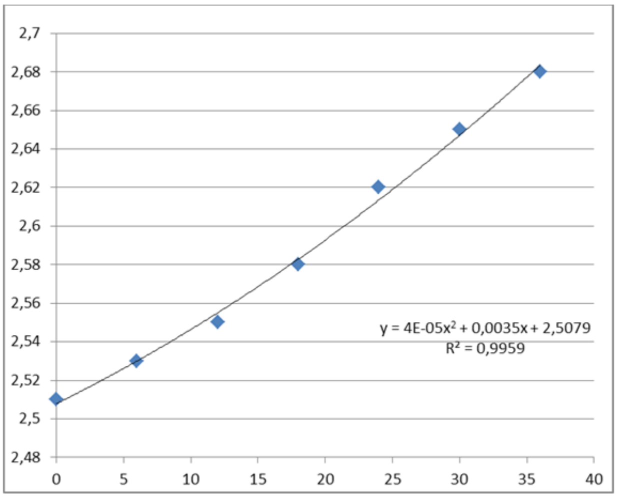

Figure 2. Average aortic enlargement estimation using a second-order polynomial regression analysis

According to the above analysis, the critical phase of the abdominal aorta enlargement of d = 5cm can expect it to come after 210 months or 17.5 years (Figure 2.).

5. Discussion

The onset of cardiovascular disease is a consequence of many risk factors. Two groups of risk factors have been identified, leading to an acute cardiovascular incident. They are divided into preventable and non-preventable, that is, conventional (nicotinic, arterial hypertension, hyperlipidemia, low level of high density lipoprotein (HDL), higher low density lipoprotein (LDL), diabetes mellitus), predisposing (obesity, physical inactivity, positive family history of cardiovascular disease, socioeconomic and behavioral factor, insulin resistance) and new (obstructive sleep apnea, C reactive protein, fibrinogen, homocysteine, lipoprotein A, familial hypercholesterolaemia, familial hyperlipidemia, familial deficit of HDL, kallikrein, matrix metalloproteinase-9 (MMP-9), galectin-3, protein S, protein C, citrate, valine, leucine, isoleucine, alanine, homocysteine, fibrinogen and iron levels) [9], [10], [11]. Prevention of any of these risk factors is a goal in daily medical clinical practice.

The blood flow through the blood vessel is physiologically laminar when each layer remains at the same distance from the blood vessel wall, and the central layer remains in the center of the blood vessel [8]. When blood flow becomes too large, when blood flows through the narrowed part of the vessel, when it suddenly turns or passes over rough surfaces, the flow can become turbulent or irregular, and when flowing, it generates rotational currents [8]. Then the resistance to blood flow is much higher [8]. The tendency of turbulent movement increases in proportion to the speed of blood flow, blood pressure and blood density, and it is inversely proportional to the viscosity of the blood [8]. That leads to an increase in arterial pressure, which is one of the etiological factors for the development of a cardiovascular incident [4], [8].

The flow rate also affects the blood vessel itself, and leads to remodeling and has an effect on the atherosclerotic process itself (atherosclerosis forms the basis of about 80% of cardiovascular diseases) [9], [10], [12]. Violation of the architecture of the wall itself leads to the occurrence of turbulent blood flow, which also represents an atherothrombotic factor [12]. The impact of noise can therefore be brought about by the rise in cardiovascular risk and the acute cardiovascular incident and it must be thought of within the factories where the noise-producing machines are located [12], [13], [14].

Accelerated blood flow can be understood as a risk factor for arterial hypertension, and the noise can be classified as an etiologic factor for arterial hypertension, confirming noise as a factor that leads to increased cardiovascular risk. Babisch also linked noise and increased cardiovascular risk [2]. Wu et al. also mentioned noise, as the etiologic factor of cardiac pathology, and their research also put focus on occupational noise, the noise in working conditions [6]. Tomei et al. also found in their meta analysis the association between cardiovascular abnormalities and chronic occupational exposure to noise [15]. Cayir et al. found that occupational noise as continuous noise in the working environment, is associated with higher risk of development of arterial hypertension in young adults, or that it may even be a precipitating factor for hypertension [16].

In addition to hypertension, there is an increase in tachycardia (which is again associated with its complications), as well as on atherosclerotic process and atherothrombosis [2], [3], [15], [16]. This all calls for a very serious grasp of noise, especially noise in the workplace, occupational noise. Limiting work in these conditions (day-time limitations), as well as the appropriate equipment, must be part of the conceptual design plan for this type of work environment [13]. Increase of blood pressure leads to hypertrophy of the left ventricle, which is one of the risk factors for aortic diameter enlargement [17]. In this research was analyzed the diameter of the ascending aorta which depends on many factors. The risk of dissection of the thoracic aorta depends strictly on the diameter of the aorta [18]. The fact is that with increasing blood pressure, the diameter of the aorta itself increases, and the purpose of the research was to show when the aorta would reach a diameter that presents a risk for aortic dissection if human is exposed to noise (the enlargement of diameter of 5cm can be expected in 210 months or 17.5 years). Of course, the age of the subjects, gender (in our study, all respondents are male, due to the nature of the job), the existence of cardiovascular and other comorbidities, physical constitution, physical activity, lifestyle, consumption of cigarettes, as well as the genetic background that should be taken into account when we talk about aortic dissection.

This research shows that noise exposure can also be considered as one of the risk factors that will lead to dilatation of the ascending aorta. It is also important to emphasize that these patients were not under pharmacological therapy, which can also stabilize the aortic wall itself, reduce the progression of the atherosclerotic process, and reduce the effect on the heart muscle through stabilization of arterial blood pressure. Altogether, continuous exposures to noise can also be considered as one of the risk factors of the cardiovascular event, and this must be thought of in contemporary medicine, and prevention should be taken into account limiting the volume of noise, both in daily life and in the planning of working conditions.

Our article presents solution for evaluation of blood velocity in any time interval, which is something we can use in education and in everyday work.

6. Conclusion

During three years of prospective monitoring, there has been a clear influence on the velocity of blood flow through the aorta and, consequently, to the cardiovascular system.

Prevention of changes in the cardiovascular system is considered imperative, and the limitation of noise levels and the length of noise exposure must be established as factors that must be planned when building a work environment.

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