

# Studying Changes of the Effective Radius in Blood Vessels after Exposure of Lower Extremities to Periodical Mechanical Vibrations

Nahirniak V.<sup>1\*</sup>, Kusniak N.<sup>2</sup>, Kashperuk-Karpiuk I.<sup>3</sup>,  
Andrushchak L.<sup>4</sup>, Protsak T.<sup>5</sup>, Pentelejchuk N.<sup>6</sup>

## ABSTRACT

**Background:** Previous studies demonstrated a health improving effect in patients underwent an automatic vibratory massage taking 10 minutes. One of reasons that may explain a healing effect of the automatic massage is a stimulated increase in both blood circulation through vascular system and effective size of blood vessels.

**Objective:** This paper aims to quantify a contribution of the automatic mechanical massage of lower extremities into the observed reduction in arterial blood pressure and explain this effect.

**Material and Methods:** In our experimental study, the lower extremities of male and female patients were exposed to low frequency (12 Hz) mechanical vibrations for 10 minutes and the change in systolic and diastolic arterial blood pressures before and after this procedure was measured.

**Results:** The experiments showed there is a reduction in systolic and diastolic arterial blood pressures after vibrational massage. There were corresponding  $3.5 \pm 1.8$  mmHg and  $3.1 \pm 1.6$  mm Hg arterial blood pressure reductions among men and  $5.5 \pm 3.2$  mm Hg and  $2.2 \pm 1.2$  mm Hg reductions among women.

**Conclusion:** We explained this effect by increasing effective radius of blood vessels. Based on the Hagen-Poiseuille equation, we made estimates for the relative change in the effective radius of blood vessels. They gave the 0.7% and 1.3% increases in the effective radius of blood vessels in lower extremities in men during systole and diastole, respectively, and the corresponding 1.1% and 0.6% increases in the effective radius of blood vessels of lower extremities in women during the same periods.

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## Keywords

Blood Pressure; Low Frequency Mechanical Vibrations; Whole Body Automatic Massage; Hypertension; Blood Circulation Improvement; Cardiovascular System

## Introduction

Many previous studies showed that an automatic massage lasting 10 minutes produces a health improving effect in patients [1-6]. Patients admit a feeling of invigoration and energy, vitality, reduced fatigue, and a body-wide sense of relaxation after a single automatic massage. After a series of massages, they admit the general

<sup>1</sup>PhD, Department of Biophysics and Medical Informatics, Bukovinian State Medical University, Chernivtsi, Ukraine

<sup>2</sup>MD, Department of Surgical Dentistry and Maxillary Surgery, Bukovinian State Medical University, Chernivtsi, Ukraine

<sup>3</sup>PhD, Department of Anatomy, Topographic Anatomy and Operative, Bukovinian State Medical University, Chernivtsi, Ukraine

<sup>4</sup>PhD, Department of Histology, Cytology and Embryology, Bukovinian State Medical University, Chernivtsi, Ukraine

<sup>5</sup>PhD, Department of Human Anatomy, Topographic Anatomy and Operative Surgery, Bukovinian State Medical University, Chernivtsi, Ukraine

<sup>6</sup>PhD, Department of Histology, Cytology and Embryology, Bukovinian State Medical University, Chernivtsi, Ukraine

\*Corresponding author:  
V. Nahirniak  
Department of Biophysics and Medical Informatics, Bukovinian State Medical University, Chernivtsi, Ukraine  
E-mail: volnag@gmail.com

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improvement of health, increased physical activity, and reduction of chronic pains in joints.

Studying the effect of mechanical vibrations on the physiological activity of both animals and people has a long history and is represented in numerous publications. There was an influence of low-frequency vibrations (60 Hz) on the peripheral blood circulation in humans. The growth of a blood flow and the increase in diastolic pressure in the vascular system were observed in people exposed to mechanical vibrations [1]. The authors noted that the increase in blood circulation is not only associated with metabolic requirements of tissues. One of the factors improving the repair of injured tissues is the blood supply to the affected area. Previous studies have shown the effect of periodic mechanical oscillations in low frequency (20-60 Hz) on peripheral blood flow (14%), diastolic pressure, level of carboxyhemoglobin, and transverse size of human blood vessels.

Well-developed muscles and vasculature and also unrestricted blood circulation promote faster recovery of body tissues [2]. Physical exercises can increase a size of capillaries by 100 times. Rhythmic muscle contractions accelerate the peripheral blood circulation. Studies have revealed that low-frequency (26 Hz) vibrations of the whole body for 9 minutes increase the blood flow and the volume of blood in the muscles of the lower extremities [2].

It was confirmed that the use of low-frequency mechanical vibrations helps in the elimination of chronic pain in a lower part of spine [3]. In this work, the increase in heart rate and blood pressure due to periodic mechanical vibrations was recorded. Increased blood pressure and heart rate by an average of 10 percent was recorded due to a transfer of low frequency vibrations (15 Hz) through a human hand into a chest lasting approximately 3 minutes [4].

There was no significant change in blood pressure and heart rate in the group of people after their exposure to a 5-minute session of

mechanical vibrations with frequency of 40 Hz [5]. However, the measurements were conducted after the 5-minute break in contrary to our studies when the measurements were conducted right after the automatic massage. Increased blood flow was observed which the authors attributed to the physiological changes in the peripheral circulatory system. It was noted the positive effect of mechanical vibration on the diameter of the arteries and a lack of vibrations impact on body temperature [6].

One of the reasons explaining the healing effect from the automatic vibrational massage is the stimulated increase in blood circulation through vascular system. In our work, a quantitative study of the impact of periodic low frequency mechanical vibrations (720 oscillations per minute) on the relative change of the radius of blood vessels in lower extremities in men and women was conducted. First, we measured the change the arterial blood pressure and the heart rate. Based on the obtained results on blood pressures, we made quantitative estimates for the relative change in effective sizes of blood vessels in lower extremities. The size increase may explain the increased blood circulation in lower extremities.

## Material and Methods

In our experimental study, the planar mechanical vibrations were generated by the industrial massager Vibro STSEK S780 model manufactured by Tianshi (Tianjin, China). The photograph of the apparatus with a patient is shown in Figure 1.

The patients were sitting in a chair with their feet soles positioned on the vibrational platform as it is shown on Figure 1. The duration of vibrational massage was controlled by the built-in timer. The central vibrating platform generates vibrations in two planes with amplitudes of 6 mm, approximately. The frequency of vibrations is fixed and equal to 720 vibrations per minute (12 Hz).

The personal blood pressure monitor, Rossmax MS60, (Taipei, Taiwan) was used for



**Figure 1:** A patient sitting in a chair with feet soles positioned on the vibrating platform.

pressure measurements. The arm cuffs were positioned at 2 cm above the elbow of the left hand. In order to increase the accuracy of blood pressure measurements, they were conducted as follows. The pressure was measured twice before vibratory massage session in intervals of 2 minutes. The Interval was necessary to restore blood circulation in hand after the first measurement. The obtained results were averaged. Patients had rested on a chair for 5 minutes before the first pressure and heart rate (HR) measurements were conducted. The measurement of blood pressure and heart rate was repeated right after the completion of vibratory massage. It was noted that within 5 minutes after the massage, blood pressure and heart rate returned to its previous normal values. This measurement protocol was chosen after preliminary studies. Processing of results was conducted in MS Excel 2010 (Redmond, WA, USA).

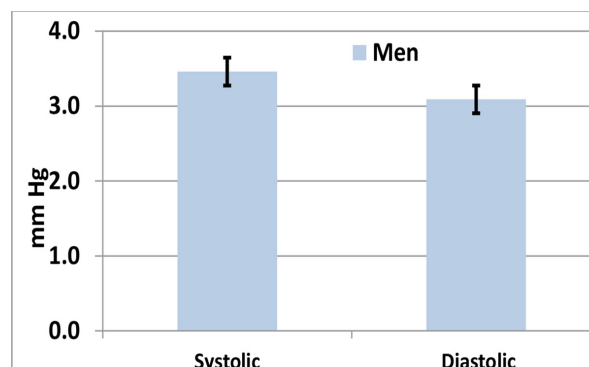
The target group included 16 men and 14 women aged from 20 to 60 years. Participants included both hypotensive, hypertensive patients and people with normal blood pressure. Most of them denied a regular use of medica-

tions regulating blood pressure. Their weight ranged from 70 to 126 kg.

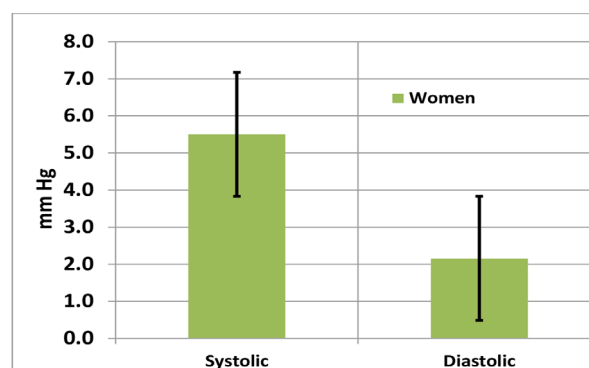
## Results

The observed individual decreases in the men and women arterial blood pressure are shown in Figures 2 and 3. The average results causing a decrease in systolic and diastolic blood pressures are shown with corresponding mean square errors. Increased heart rates were  $1.2 \pm 1.0$  and  $1.2 \pm 2.0$  beats per minute for women and men, respectively.

The averaged numerical results on the reduction in blood pressure are summarized in Table 1. They are shown along with the stan-



**Figure 2:** Individual reduction in systolic and diastolic arterial blood pressures among participating men. The data are shown along with standard errors.



**Figure 3:** Individual reduction in systolic and diastolic blood arterial pressures among participating women. The data are shown along with standard errors.

**Table 1:** Observed values of the decreased systolic and diastolic pressures and heart rate in men and women after exposure of lower extremities to the automatic massage. The data are presented along with standard errors.

	Decrease in systolic pressure ( $\Delta p_s$ ), mm Hg	Decrease in diastolic pressure ( $\Delta p_d$ ), mm Hg
Men	3.5±1.5	3.1±0.6
Women	5.5±0.9	2.2±0.8

standard errors.

Furthermore, we have noticed a minor increase in a heartbeat rate. The change in heart rate in both groups was marginal and comparable with standard deviation in measurements.

There are a few factors which may contribute to the change of blood pressure. According to the Hagen–Poiseuille equation, the systolic and diastolic blood pressure are given by the following formula:

$$p = \frac{8\eta LCO}{\pi R^4} \tag{1}$$

where  $\eta$  is viscosity of blood,  $R$  is the effective radius of vascular system blood vessels, and  $L$  is its effective length. The cardiac output ( $CO$ ) is the product of the stroke volume ( $SV$ ) and the heart rate ( $HR$ ):

$$CO = SV \cdot HR \tag{2}$$

As one can see, there are a few factors which may result in the observed blood pressure changes, including viscosity of blood, a radius of blood vessels, and a cardiac output. According to the equation (1), the relative change in the radius may be estimated as follows:

$$R = \sqrt[4]{\frac{8\eta LCO}{\pi p}} \tag{3}$$

$$dR = -\frac{1}{4} \sqrt[4]{8\eta LCO} p^{-\frac{5}{4}} dp \tag{4}$$

$$\frac{dR}{R} = -\frac{1}{4} \frac{dp}{p} \tag{5}$$

In this study, mainly blood vessels of feet are affected by the vibrational massage. On the other hand, the heart and main vessels (aorta and vena cavae) are not affected by mechanical vibrations [7]. For this reason, we assume that a stroke volume and a heart rate do not change after the action of mechanical vibrations. According to the formula (5) and the results of our measurements, we calculated the relative change in effective radius of blood vessels in lower extremities. The average results of these calculations are shown in Table 2.

### Discussion

The volume and quality of the blood flow are dependent on the state of the blood vasculature [8]. Constriction of blood vessels and an increase of peripheral resistance make blood circulations slow and the restoration ability of tissues worst, and finally lead to developing hypertension [9]. Improvement in blood circulation and the state of blood vasculature is important factor in prevention of chronic high blood pressure. In this work, we studied one of the non-therapeutic methods causing promising results in improvement of blood vasculature state and in overall treatment of hypertension.

**Table 2:** Calculated relative increase in the effective radii of blood vessels of lower extremities after their exposure to the automatic vibrational massage.

	Change during systolic period ( $\Delta R/R$ ),%	Change during diastolic period ( $\Delta R/R$ ),%
Men	0.7	1.3
Women	1.1	0.6

In our experiments, the position of the patient on the vibrating platform was chosen to eliminate the substantial influence of vibrations on the thoracic and abdominal areas of a patient. Under these conditions, the cardiac output of the heart in the patients remains unchanged during the entire period of the experiment.

Theoretically, according to the Hagen -Poiseuille formula, an increase in the volume of blood flow in the bloodstream is directly proportional to the blood pressure gradient  $\Delta p$  [10]:

$$CO = \frac{\pi R^4 \Delta p}{8\eta L} \quad (6)$$

where  $\eta$  – dynamic viscosity of blood,  $L$  - is an effective length of a circulatory system,  $R$  – an effective average radius of blood vessels,  $CO$  - is a cardiac output of a heart. This applies to both systolic and diastolic periods in a cardiac cycle. The mechanical vibrations primarily affect the vasculature of lower extremities in patients and did not affect thorax and heart. The choice of the patient's position was made in order to keep the cardiac output unchanged in the experiment.

Under these conditions, the measured decrease in blood pressure  $\Delta p$  may be related to the increase of the size of blood vessels  $R$  (6). The measured reductions in systolic and diastolic blood pressure allowed us to make quantitative estimates for the relative increase in the effective size of blood vessels in feet during systole and diastole.

## Conclusion

The results of our work demonstrated the decrease in both systolic and diastolic arterial blood pressure after exposure of the lower extremities in our patients to the periodic mechanical vibrations of low frequency. We assumed that the registered decrease in blood pressure is a result of the increase in effective radius of blood vessels. Under these assumptions and using the Hagen–Poiseuille equa-

tion, we calculated the relative change in the effective radius of blood vessels.

Automatic vibrational massage demonstrates healing ability. Mechanical vibrations facilitate the circulation of blood in muscle tissues especially in peripheral areas suffering from low oxygen levels. This therapy potentially increases the oxygen content in blood and helps with cell regeneration.

Results showed some enlargement in the effective radii of blood vessels in lower extremities. From this standpoint, the automatic vibrational massage may be considered as an adjuvant therapy against blood hypertension since widening the blood vessels leads to lowering the overall blood pressure.

The further studies might reveal the relation between the duration of vibrational massage or its frequency and the change in the radius of blood vessels.

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## Conflict of Interest

None

## References

1. Button C, Anderson N, Bradford C, Cotter JD, Ainslie PN. The effect of multidirectional mechanical vibration on peripheral circulation of humans. *Clin Physiol Funct Imaging*. 2007;**27**:211-6. doi: 10.1111/j.1475-097X.2007.00739.x. PubMed PMID: 17564669.
2. Lohman 3rd EB, Petrofsky JS, Maloney-Hinds C, Betts-Schwab H, Thorpe D. The effect of whole body vibration on lower extremity skin blood flow in normal subjects. *Med Sci Monit*. 2007;**13**:CR71-6. PubMed PMID: 17261985.
3. Wang L, Zhao M, Ma J, Tian S, Xiang P, Yao W, et al. Effect of combining traction and vibration on back muscles, heart rate and blood pressure. *Med Eng Phys*. 2014;**36**:1443-8. doi: 10.1016/j.medengphy.2014.08.008. PubMed PMID: 25263929.
4. Jebur AA, Abed AY. Effect of Vibrations Transmitted Through Hand on Human Body and Blood Pressure. *International Journal of Advances in En-*

- gineering Science & Technology*. 2013;**3**:47-56.
5. Robbins D, Yoganathan P, Goss-Sampson M. The influence of whole body vibration on the central and peripheral cardiovascular system. *Clin Physiol Funct Imaging*. 2014;**34**:364-9. doi: 10.1111/cpf.12103. PubMed PMID: 24237890.
  6. Cochrane DJ, Stannard SR, Firth EC, Rittweger J. Comparing muscle temperature during static and dynamic squatting with and without whole-body vibration. *Clin Physiol Funct Imaging*. 2010;**30**:223-9. doi: 10.1111/j.1475-097X.2010.00931.x. PubMed PMID: 20491843.
  7. Nahirnyak VM, Branashko AE, Kifichuk IG. Influence of periodic mechanical vibrations on human arterial blood pressure. *Buk Med Herald*. 2017;**21**:96-9.
  8. Folkow B, Neil E. *Circulation*. New York: Oxford University Press; 1971.
  9. Mayet J, Hughes A. Cardiac and vascular pathophysiology in hypertension. *Heart*. 2003;**89**:1104-9. doi: 10.1136/heart.89.9.1104. PubMed PMID: 12923045; PubMed PMCID: PMC1767863.
  10. Waxman MA. Using physics to investigate blood flow in arteries: A case study for pre-med students. *Am J Phys*. 2010;**78**:970-3. doi: 10.1119/1.3379292.