Original Article

Using the Blood Coagulation Factors as a Predictor Component of the Occupational Vibration Exposure

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Abstract

Background: Exposure to hand–arm vibrations higher than permissible standard rates can have destructing effects on workers' health. Pneumatic hammers are among the tools that are used in civil and industrial projects, transferring high vibration acceleration to the workers. This study has considered the probable effects of hand–arm vibrations on the performance of blood coagulation factors in the workers using this tool and exposed to high vibration acceleration. **Methods:** Five new workers without any experience in exposure with hand–arm vibrations were selected for this interventional study. Blood sample was taken from each worker before they started working for the required analysis. Sampling was repeated in two other stages in 2-month intervals from the first sampling, whereas the workers were then experienced in working with pneumatic hammers. Measuring the vibration of the pneumatic hammer was done according to ISO 28927-10 standard. **Results:** The point of measuring the vibration acceleration was selected close to the hand, in accordance with the standard. Regarding the exposure time of the workers, the amount of vibration acceleration was obtained 15.54 m/s^2. Activated partial thromboplastin times of four samples in the second and third stages have shown increases in comparison to the first stage in that respect. On the other hand, a number of red blood cells, white blood cells, and platelets did not show a consistent trend in the three stages. **Conclusions:** The considered samples showed longer time for blood coagulation as compared to the reference time. Thus, it can be concluded that the main reason is the acceleration in three different coordinate axes of x, y, and z. Hence, the values beyond permissible standard rate of hand–arm vibration in 8 h shifts affect the blood parameters, among which the considered coagulation parameters in this study showed more tangible changes in that respect.

Keywords: *Blood coagulation, occupational exposure, vibration*

Introduction

According to the nature of work in industry and construction, the people occupied in industrial and nonindustrial environments are exposed to vibrations. Vibration is an occupational hazard. Extensive occupational exposure to vibrations is related with the emergence of some diseases. The two main spectra of vibration include the whole body vibration and hand–arm vibration. Three billion workers are working in the world, 25% of whom are exposed to vibrations.[1] Exposure to both types of occupational vibrations ends up in improper effects on musculoskeletal, cardiovascular and nervous systems, blood biochemical condition, and physiological as well as psychological aspects.[2] Human reaction to vibrations depends on the amplitude, frequency, and exposure time of vibration and the sensitivity of tissue.[3] Human exposure to hand–arm vibration has extensive complications. Entrance of vibration occurs at three different directions, and vibration frequencies may include an extensive period. The vibration received by an operator depends on the type of activities (skill) that are done and differs with regard to his fingers' dynamic response as well as his hands and arms.[4] The main sources of exposure to hand–arm vibration include handheld power tools, conducting mechanical equipment with hands, and holding raw materials during mechanical processes.[5] Working with power tools such as hammers and drills is among demanding jobs, requiring extensive physical force by the operator. Generally, the rate of vibration acceleration of hammer drills is 8–16 m/s^2 and that in pneumatic hammers for stone is 14–20 m/s^2.[6] Vibration in pneumatic hammers includes bilateral movements in the handles, occurring when some forces are imposed to the device in different directions and magnitudes to operate it.[7] This type of exposure to pneumatic

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hammers can cause disorders due to hand–arm vibrations after hours of exposure for a week to even some months.[6]

Counting blood cells is considered as one of the most popular laboratory tests, nowadays. This test provides information about the production of blood cells, evaluating the capacity of oxygen transportation of the person through red blood cell (RBC), hemoglobin, hematocrit indexes, and information about white blood cells (WBCs). Platelets that are considered as the smallest blood cells have a vital role in ceasing blood. In addition to the responsibility for coagulation factors, platelets have hemostasis role in small and medium vessels and arteries. Platelets are aggregated and stick together to provide the primary obstacle against damaged parts.[8]

Blood coagulation starts within a few seconds after vascular damages, being one of the fastest tissue restoration systems in human body. The main aim of coagulation is blocking the damaged vessel. Blockage is done by aggregation of platelets at the damaged area, and then in the next stage, it is stabilized by the formation of fibrin network; the two actions are known as primary and secondary hemostasis, respectively.[9] Plasma coagulation function can easily be assessed by some simple tests such as activated partial thromboplastin time (aPTT). The period for aPTT is 30–40 s.[10] aPTT is a useful test for analyzing and evaluating the secondary hemostasis. This test can identify inherited or acquired deficiencies regarding V, VIII, IX, X, XI, and XII coagulation factors, prothrombin, and fibrinogen.[8] The end point in the test is the time in formation of fibrin clot (in seconds) that can be found by visual, optic, or electromechanical instruments. aPPT is among the easiest and most available coagulation tests and applied for early diagnosis for coagulation disorder due to injuries. While aPPT is considered as a proper predictor for the risk of intensity and mortality in injured patients, but it may not be able to express precise and correct explanation from the coagulation functional disorder.[10]

Effect of acute exposure to vibration resulted in fingers' blood flow reduction. The greater the magnitude of vibration, the greater the reduction in finger blood flow.[11]

Repetitive exposures to vibrations damages surface vessels and functional disorders of nerves in hands and fingers.[12]

Blood coagulation changes in patients affected to secondary Raynaud phenomenon due to vibrations is properly identified. Studies on blood coagulation parameters in operators of vibrating tools have led to conflicting results. Sroczynski *et al*. (1979) reported the increase in fibrinogen and reducing time of plasma recalcination in exposed workers to vibration, while Zedda *et al*. (1968) observed hypocoagulability in Italian miners.

Regarding the effect of vibration on blood and its parameters in patients who suffer from the vibration syndrome, Shunto *et al*. (1991) proved that platelet adhesion, aggregation activity, and plasma Willebrand factor have increased, age of the platelets are decreased, and blood viscosity has shown increasing trend.

The purpose of this study is to analyze the effect of hand–arm vibrations on blood variations during three stages with 2-month intervals in workers using a hammer, who have recently started their physical activities and have extensive daily exposure to hand–arm vibrations.

Methods

Blood sampling

An interventional study was conducted. The experimental group included five men, who had no experience in working with pneumatic tools and had no exposure to hand–arm vibrations, having the intention to work with pneumatic hammers. The inclusion criteria for the experimental group to this study were no smoking (the rate of hemoglobin in smoking people may be incorrectly high[8]), lack of consuming nonsteroid anti-inflammatory medicine (ibuprofen, diclofenac, aspirin, etc.) and anticoagulants (such as warfarin and heparin), not having chronic cardiovascular diseases, and workers not being affected to congenital diseases related to blood coagulation such as hemophilia. Table 1 shows general information about the workers in this study.

Blood samples were taken from the cubital veins of the workers' arms by experienced laboratory technician before they start working with pneumatic hammers. In the next stage (second stage) of the study that was 2 months after the first sampling procedure, another sample was taken from the blood of each worker. The last blood sample was taken 4 months after the first sampling (2 months after the second sampling). The blood samples were collected by the related specialist at the civil and construction area, where the workers were working. It is to note that, by the second stage, the workers were exposed to hand–arm vibrations for 2 months, and by the third stage, they were exposed to the vibrations for 4 months. After each sampling process, the samples were transported in laboratory conditions, and the required tests were done on them for analyzing aPTT, frequency of RBCs, and frequency of WBCs and platelets.

Measuring hand-arm vibration

Measuring the vibration was done at the second stage of sampling which is 2 months after starting work by the workers with pneumatic hammers. Pneumatic hammers

Table 1: General information about the samples

	Minimum	Maximum	Mean±SD
Age	18	22	20.4±1.67
Weight	60	90.7	68.82±12.46
Height	163	178	171.6±6.02
BMI	18.94	29.62	23.38±3.4

BMI=Body mass index, SD=Standard deviation are known as the main source for generating noise and vibrations. Pneumatic hammers are among the power tools that are controlled and conducted by the operator.[7] The considered pneumatic hammer in this study was produced by Atlas Copco (Model: 658L) with the weight of 24 kg. Sound and vibration analyzer (BSWA 801) made in China was used to measure the vibration acceleration of the hammer. Measuring the vibration transmitted to the hand was done according to ISO 28927-10 standard.[13] According to this standard, measuring on the vibrating surface should be done on the gripping point of the tools, if possible, i.e., the place that the operator has held the tool and imposes the required pressure. Two points on the pneumatic hammer handle are considered in the standard for measuring the vibration acceleration. Up to its possible extent, the first recommended point should be near the hand and the required sensor to be placed between the thumb and the index finger. The second point is a side point that, if possible, should be near the inner end of the hammer handle. If the first suggestion on the vibration generator cannot be used, we shall use the second recommended point.

According to the standard, the operators had straight standing position and held the hammer vertically downward, in the test process. Minimum time for each test is 8 s except if the device has high power and the component under operation is small. Different operators who had adequate skill for controlling and holding the pneumatic hammer were used in the study. We repeated three sequences of experiments by the aid of three different operators (among the five selected ones), and the measurements were done 5 times for each sequence. The sensor was located between the thumb and the index finger of the workers, for each measurement. Then, we recorded the numbers shown in the vibration level meter displayed unit during the time that the hammer was working. It is to note that the three operators used to control the pneumatic hammer with similar hand position. The mean root square values of three coordinate directions were measured for each time of measurement, using formula (1) and the arithmetic mean of the vibration acceleration was determined for each test.

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

a_{hwx}, a_{hwy}, and a_{hwz} are accelerations values in the x, y, and z directions, respectively.[3]

Finally, the arithmetic mean was calculated for each test, and the rates of vibration acceleration for the three operators were obtained for one hand position.

The European Parliament has published the directive "44/2002/EC" for the health and safety limits on exposure to 8 h acceleration. The permissible 8 h acceleration for permissible exposure limit value indicates ELV = 5 m/s^2 in that directive, and exposure action value is EAV = 2.5 m/s^2.[14] The 8 h acceleration is calculated according to this directive based on ISO 5349 (2001). By transforming the daily vibration to the reference 8 h vibration, this standard prepares it for evaluating the exposure level using formula (2).[15]

$$A(8) = a_{\text{hv}} \sqrt{\frac{T}{T_0}} \qquad (2)$$

a_{hv} in relation (2) is the calculated vibration acceleration of the source (m/s^2), T indicates the exposure time with the vibration, and T_0 shows the reference 8 h time (28800 s).[16]

Results

Pneumatic hammer vibration acceleration

Measuring the vibration acceleration was done in virtue of ISO 28927-10 standard, and the place of measurement was the first recommended point, which was selected near as possible to the hand, and the hand–arm sensor was placed between the thumb and the index finger. The exposure time of workers working with the hammer to hand–arm vibration was estimated to be 4.3 h/day on average (equal to 15,480 s). The rate of nonweighted acceleration of the considered pneumatic hammer in this study with 1.3-octave band for 15,480 s exposure was 15.54 m/s^2 with regard to the hand position of the three different workers.

Blood parameters

Table 2 shows the results obtained from the sample blood tests and different aPTTs. According to the results obtained from the five workers in this study, apart from the fifth sample, in which its aPTT3 had decreased as compared to that in the second stage (aPTT2), the other four samples showed increasing aPTT in the two stages as compared to the first stage (before working with the pneumatic hammer and exposure to hand–arm vibration). Analysis of the data resulted from the experiment was done by IBM SPSS statistics for windows, version 21 (IBM Corp., Armonk, N.Y., USA). Variance analysis with repetition of observations showed that the mean aPTT was not similar in the considered three occasions ($P = 0.04$). Moreover, least significant difference *post hoc* tests showed that mean aPTT in the second stage ($P = 0.02$), and the third stage ($P = 0.05$) had significant increase as compared to that in the first stage. However, no significant difference was observed between the second and third aPTTs ($P = 0.16$).

Table 2: Results from the three stages of sample blood tests and activated partial thromboplastin times

Samples	aPTT1 (s)	aPTT2 (s)	aPTT3 (s)
Sample number 1	44.40	45.00	45.30
Sample number 2	37.00	37.70	38.50
Sample number 3	44.30	45.80	46.20
Sample number 4	39.30	40.90	42.20
Sample number 5	43.40	46.20	45.30
Mean±SD	41.68±3.34	43.12±3.69	43.60±3.25

aPTT=Activated partial thromboplastin times, SD=Standard deviation

Table 3 shows the results obtained from testing RBCs, WBCs, and platelets in the three stages of the study.

Table 3 depicts the results from testing RBCs. The average number of RBCs in the second stage is increased as compared to that in the first stage, but it had a reducing trend in the third stage and got closer to the primary amount in the first stage. Moreover, the same trend is observed in the obtained results about testing the WBCs. Primarily, the average number of WBCs had an increase in the second stage relative to that in the first stage, but it was reduced in the third stage. The average number of platelets in the second stage had a negligible increase as compared to that in the first stage, as can be seen from the results obtained from testing blood cells in Table 3. However, this rate demonstrated a considerable reduction in the third stage. Variance analysis with repetition of observations showed that the average numbers regarding RBCs, WBCs, and platelets had no significant differences at different times ($P = 0.67$, $P = 0.17$, and $P = 0.69$, respectively).

Discussion

The obtained vibration acceleration from measuring hand–arm vibration acceleration was compared with the permissible values recommended by the European Parliament and the directive 44/2002/EC. In the directive, the permissible 8 h acceleration for permissible exposure limit value indicates ELV = 5 m/s^2 in that directive, and exposure action value is EAV = 2.5 m/s^2. It is clear that vibration acceleration of 15.54 m/s^2 is much higher than the determined permissible 8 h acceleration for permissible exposure limit. Pneumatic tools are considered as the most vibrating power devices. Pneumatic hammers and destruction hammers, among the 12 tools analyzed by López-Alonso *et al.*, showed the highest vibration acceleration, and even the lowest vibration acceleration in them exceeded the daily permissible limit of 2.5 m/s^2.[15]

As previously stated, the reference and normal period of aPTT is 30–40 s. Regarding the obtained results from analysis of blood coagulation time in the workers working with hammers during 4 months of exposure to hand–arm vibration, four out of five samples (samples 1–4) showed increasing the aPTT in the second and third stages as compared to the first stage (before start working with pneumatic hammers and exposure to hand–arm vibration). According to Table 2, four workers showed longer blood coagulation time relative to the reference aPTT before the exposure, or this time increased after the exposure. Most of the increase in the time for blood coagulation based on aPTT was observed in the fourth worker during three stages of sampling and 4-month working with the pneumatic hammer. This 2.9 s increase can be related to hand–arm vibration more than the permissible exposure limit. Sample no. 5 showed a 2.8 s increase in the second stage, after 2 months of the required exposure, but as opposed to other samples, we observed its reduction in the third stage. Stressing that the highest time increase (2.9 s) occurred in the fourth sample during 4 months of exposure, we however observed the 2.8 s increase in aPTT in sample no. 5 in 2 months of exposure.

By the fulfilled investigations, it was found that studies on the blood coagulation parameters of the operators of vibrating tools showed contradictory results. In a study by El-Said *et al.*, 77 people were exposed to whole-body vibration, and 27 people were exposed to hand–arm vibration. A considerable increase was observed in prothrombin time (PT) in the samples that were exposed to hand–arm vibration, in comparison to the control group of the study. Based on the study by Khalid Al-Saeed, the other factors in analyzing the blood coagulation time, i.e., the PT, in the exposed group to vibration had an increase, as compared to the control group.[2] The aPTT was analyzed in the current study, and the increase in it was observed.

In a study by Bovenzi *et al*. (1983), coagulation parameters in operators of pneumatic manual tools were compared with the worker without exposure to vibrations. The rates of blood coagulation, including aPTT, were similar in both groups. In his studies and based on Taylor grading system, Bovenzi reported that 95% of the exposed operators were affected to different levels of vibration white fingers.

Accordingly, the changes in the three parameters analyzed in this study, i.e., RBCs, WBCs, and platelets had no stable trend, and the significance of the results was not approved due to the performed statistical analysis. However, the fluctuations of the parameters and the trend created on blood due to hand–arm vibration exposures are the points of concern to be considered.

Table 3: Results obtained from testing red blood cells, white blood cells, and platelets

Samples	RBC 1 (10^{*6}/µL)	RBC 2 (10^{*6}/µL)	RBC 3 (10^{*6}/µL)	WBC 1 (10^{*3}/µL)	WBC 2 (10^{*3}/µL)	WBC 3 (10^{*3}/µL)	Platelets 1 (10^{*3}/µL)	Platelets 2 (10^{*3}/µL)	Platelets 3 (10^{*3}/µL)
Sample number 1	4.80	5.38	5.02	4.88	10.01	6.17	300	205	204
Sample number 2	5.35	5.23	5.26	11.94	10.56	5.54	192	302	239
Sample number 3	4.62	4.99	4.78	6.62	6.74	6.24	255	208	218
Sample number 4	5.04	5.56	4.64	7.08	8.00	5.53	313	342	186
Sample number 5	5.13	4.66	5.45	3.72	8.21	9.20	177	197	234
Mean±SD	4.98±0.28	5.16±0.35	5.03±0.33	6.85±3.15	8.70±1.56	6.53±1.53	247.4±61.55	250.8±66.64	216.2±21.8

RBC=Red blood cell, WBC=White blood cell, SD=Standard deviation

Conclusions

In this study, we evaluated the effects of hand–arm vibrations in excess of standard levels on the blood of the pneumatic hammers operators. In the primary assessments and by starting this research, we found out that most of the workers working with hammer were dissatisfied by long-time working with the hammers. This occupation is among the hard physical occupations that require high stamina. Thus, not many people are interested in working in this field, and regarding the shortage of workforce, most of the people working with hammers are transferred from a project to another, after finishing their work. To find out the effects of hand–arm vibrations on blood parameters, we defined a 4-month period and utilized the workers, who had no experience in working with pneumatic hammers. The purpose for that is analyzing the activities of workers before and during continuous exposures in the next two stages.

The considered parameters during the 4-month study included blood coagulation, number of RBC and WBC, and platelets. The blood coagulation time in the hammer workers showed a considerable increase during the study. aPTT test evaluates prekallikrein and Kininogen with high molecular weight, V, VIII, IX, X, XI, and XII factors, prothrombin, and fibrinogen.[10] The mechanism of this type of vibration on blood is not properly known. However, regarding the aPTT test parameters, hand–arm vibration affects the parameters, increasing the time of blood coagulation in accordance with the results stated in this study. Further investigations are essential for better comprehension of the effects of vibration on the required parameters.

Comparison of the results of the present study and the study by El-Said *et al*. is difficult, since the laboratory tests were different in them, and the samples in this study were under consideration in a long process, having no abnormal exposure to the vibrations before starting the study. Anyhow, the considerable point is increasing the time of blood coagulation in both studies.

Definitely, the physical conditions of operators and their experiences have great effects on their general conditions, regarding the exposures and the effects of vibration. However, the results from a continuous assessment of people, in such a way for them to be considered in definite intervals and under control, can be more reliable. In confirming this point, in analyzing the exposure to impact vibrations and their effects on the blood vessels and surface nerves, Krajnak *et al*. concluded that periodic exposure (15 min.) to this type of vibration has negligible effects on blood vessels and nervous system.[12] In fact, the period of exposure is quite important in analyzing exposure to hand–arm vibration, and the destructing effects of this physical factor can be revealed in the passage of time (such as hand–arm vibration syndrome and increasing the time of blood coagulation).

Changes in the number of RBC and WBC and platelets showed no fixed trends. Fluctuations of these values prohibit us from concluding about the effect of vibration on these blood components. However, the important point is stabilization of the changes, i.e., when will these fluctuations be stabilized in continuous exposure to vibrations, and in which spectrum (normal or abnormal) will this stability exist?

This study showed that excessive exposure to hand–arm vibration can make blood coagulation longer to complete. Even though this delay may not seem much of a threat to general health of workers who are exposed to this physical hazard, they should be monitored. The increment trend of blood coagulation time during contact with hand–arm vibration demonstrated in this study can harm the biochemical function of blood. We emphasize on conducting further investigations to recognize the exact function of vibration on blood cells and factors relating to coagulation of blood.

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Conflicts of interest

There are no conflicts of interest.

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