HYGIENIC ASPECTS OF OCCUPATIONAL HAND–ARM VIBRATION

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ABSTRACT

The hygienic aspects of hand–arm vibration measurement and evaluation as well as some clinical findings resulting from occupational hand–arm vibration are discussed.

The authors' data on transmission of the vibration through the body and driving point mechanical impedance of the hand as well as methods describing pathological changes are presented.

Some views on the possibilities of technical and medical preventive measures are also mentioned.

INTRODUCTION

Soon after the first pneumatic tools were introduced into use, papers on vascular disorders in the fingers of operators of these devices began to appear.[1] The decisive effects of high-frequency vibrations and muscular tension as well as the inducing effect of cold were already correctly recognized in these first studies. The corresponding disorders have subsequently been designated as vasoneurosis, angiospasm, and Raynaud's phenomenon.

In work with a vibrating object whose vibration is transmitted to the upper extremities, one must be concerned with three systems of the human organism that are attacked and may suffer damage: the vascular system, the musculoskeletal system, and the peripheral nervous system of the upper extremities.

In this paper, we do not want to deal with the various views of the pathophysiologic mechanism of these ailments. A certain disadvantage of the diagnosis is that, so far, a standard form of examination has not been elaborated to objectify damages, which would allow comparison of the incidence between countries.

CLINICAL ASPECTS AND DIAGNOSIS

From the clinical point of view, we regard the medical consequences of work involving vibration as a result of multifactorial effects. Apart from the vibration effect proper, codecisive factors are endogenous-constitutional, endogenous-acquired, and exogenous influences.

Endogenous-Constitutional Influences

With regard to the *vascular consequences*, these influences include the tendency towards a vasoneurotic response, e.g., to cold, especially expressed in neurovegetatively labile persons.

The vascular system of the upper extremities may furthermore be under the influence of certain constitutional anomalies in the region of the upper thoracic aperture where the existence of megatransversus C7 may irritate the brachial vascular plexus to enhance the tendency toward vasospasms that, naturally, have acral manifestations with certain maxima. This point is in marked association with some exogenous influences (e.g., anomalous holding of the tool in hyperabduction, for example, boring into a seam ceiling, etc.); this is a position that, especially in predisposed persons, may restrict the flow through the brachial vascular plexus. Theoretically, one may even assume some anatomic anomalies in the region of the arcus n. ulnaris and arcus n. radialis of the terminal vascular bed of the hands—but this question would require closer arteriographic studies, which we have not undertaken so far.

With reference to the *nervous system*, we would primarily like to draw attention to the possible consequences of pressure on the plexus brachialis, under the above-mentioned situation, in the upper thoracic aperture. Similarly as with the vascular system, the nervous system may also be irritated here. It is interesting in this respect that in our previous studies we could find a rather large number of megatransversus C7 or even cervical ribs in persons with damage to the nervous system resulting from work involving vibrations. As against controls, where the prevalence of this anomaly is stated to equal 5%, we found these bone anomalies in 16% of our first group of examined persons (108 individuals) and in 10.7% of our second group (137 individuals).

Another area where constitutional (physiological) anomalies play some role is that of the sulcus n. ulnaris, where excursibility of n. ulnaris from the sulcus may occur in the flexed elbow. The repeated alternating movement of flexion-extension or a prolonged static load in a position with the elbow flexed leads, in these patients, to a lasting irritation of the stem of this nerve, consequent paresthesia, and even a picture of variously developed paresis. In contrast to controls, where prevalence is stated to be approximately 12% to 18%, this anomaly was encountered in 29.9% of the 245 persons in both our sets.

Constitutional anomalies in the region of the carpal tunnel, whose diameter may be smaller (especially in women), may account for difficulties that have appeared owing to affected n. medianus manifested as the carpal tunnel syndrome. This anomaly would be difficult to objectify, but a relatively gracile constitution of the hand is surely indicative of rather narrow dimensions of the canal. It should be pointed out in this connection that similar relations may be expected in the configuration of the ulnar tunnel in the palm.

Endogenous-Acquired Influences

During a lifetime, one may incur certain diseases that may then influence the consequences of the type of work under discussion, or both situations may influence each other.

With regard to work entailing vibrations, the primary problem is the problem of the cervical spine. During the last decade, the number of vertebrogenic ailments, including discopathies of the cervical spine, has been increasing in the entire population. An affection of the cervical spine, no matter what the cause, may aggravate all the clinical consequences of damage from vibration. In our first group (n=108), praespondylotic changes (deformation of cervical lordosis, vertebral blocking, deviation of spines, single osteophytes) were found in 37% of persons and signs of osteoarthrosis and discopathy in 47%. In the second group (n=137), roentgenology revealed affection of the cervical spine in 46.9% of persons. Both figures show the number of disorders are high.

In some cases there appear, alongside vertebral findings, signs of pronounced spinal compression due to discopathy. The clinical picture then shows development of the compressive myelopathy syndrome formerly erroneously taken for an expression of the attack of vibrations themselves. In both our groups taken together (n=245), we encountered this finding 13 times, i.e., in 5.3% of cases, with five of them, after pneumoperimyelographic examination, requiring surgery for the discopathy.

The region of the elbow joint has an influence on the development of neurological complications if the joint has been affected by an arthropathic process, or epicondylar appositions have developed upon the epicondyles, or appositions have appeared at the site of insertion of the m. triceps brachii tendon. All these changes may irritate the n. ulnaris stem passing in the neighborhood, particularly so if there is simultaneous deviation of the nerve from the sulcus or if the sulcus is shallow and the immersing tendon of the m. triceps brachii compresses, by its ossified part, the stem against the bottom of the sulcus. This mechanism of damage is confirmed by palpation findings on the n. ulnaris, which is swollen, pasteous, and painful. Roentgenological changes (arthrosis ossification of the insertion and of m. triceps brachii and epicondylar appositions) in the elbow–joint region were detected in 67% of the individuals of our first group (n=108) and in 70% of the second group (n=137).

The wrist is exposed to particular stress because the grasp of the tool, the applied pressure, and the firm direction of the tool require quite an intense grip on the handle. For this reason, it is very often possible to find cases of carpal tunnel syndrome. We saw it in 21% of the first group and 32.8% of the second group of examined persons. Ulnar tunnel syndrome is less frequent; we only found it in isolated cases, moreover in combination with the carpal tunnel syndrome. The essence of these lesions is tenosynovitis, which, by its proliferative inflammation, narrows down the inner section of the tunnel and brings about compression with all its consequences on the n. medianus.

Of late, we have also given some attention to the influence of ischemisation from vasoneurosis on damage (if any) to the peripheral nerves. We were able to demonstrate that in two groups (an occupational vasoneurosis group and a group of nonoccupational developed Raynaud's syndrome) sensitive fibers were found at an initial stage of damage. The rate of conduction velocity of these sensitive fibers decreased significantly in both patient groups as compared with control groups; this decrease occurred simultaneously in the n. medianus and n. ulnaris.

Exogenous Influences

We would like to recall that the intensity and extensity of vibration transmission also depend on the quality of the material being machined. The harder the material, the firmer the grip and the greater the applied force on the tool is required; the consequent change in the muscular mass quality (tougher consistence) leads readily to transmission of vibrations upward along the hand and arm.

The influence of cold is also important, especially on the development of vasoneurotic changes. The possible favorable influence of wearing gloves is (as we see it) that they protect the hands against cold rather than that they should notably dampen the transmission of the vibration themselves.

The development of damage to the skeleton and the soft parts of the locomotive system is further influenced by the work posture. An anomalous position of the cervical spine, trunk, hyperabduction of the upper extremities in the working posture, etc., bring about situations in which these systems are affected more easily as a result of being overloaded.

We also see a certain influence of skill on lesion development. Although this point is difficult to quantify or specify with great precision, it seems beyond doubt that an untrained approach to this hard work is more apt to lead to signs of overstress, which most often appear exactly in the locomotive apparatus, as a rule under the heading of the carpal tunnel syndrome of epicondylar difficulties, with all their consequences.

Diagnosis

The diagnosis of *vasoneurotic changes* is made in Czechoslovakia by a standard method, as elaborated by Huzl,[2,3] involving plethysmographic examination before and after cooling the extremities. The individual stages of vasoneurosis are precisely characterized and the findings are well categorized. For tentative investigation, the Lewis-Prusík test is used, involving measurement of the time necessary for the return of the natural color of the finger after compression for several seconds, and the "cooling test," involving submersion of the hands into cold water (5°C) for 15 minutes and then measurement of the degree of lividity or cyanosis, if any, of the affected fingers. These aspects are also mentioned in the paper of Teisinger and Louda.[4]

To objectify structural changes of the *skeleton* and in the periarticular region, standard roentgenological projections (as generally used) are employed.

For the *neurological diagnosis*, we have standardized a method of stimulation electromyography with simultaneous examination of the transmission rate in the faster-motor and sensitive fibres. Invariably both of the nerves, n. medianus and n. ulnaris, are tested in both upper extremities.

An interesting finding in our results is that isolated pathological phenomena were found far more often only in one (mononeural) of the nerves (group 1, 25.9%; group 2, 32.1%) and seldom in both (bineural) (3.7% in group 1; 9.5% in group 2). These isolated lesions invariably corresponded to changes found at the same time in the skeleton or in the soft parts of the arm; these were descriptive of secondary nerve lesions from damage to the locomotive apparatus. On the other hand, if simultaneous lesions were found in both nerves, this finding correlated with vasoneurosis found at the same time. This fact, together with the above-mentioned experiences concerning the influence of vasoneurosis on the conduction velocity in the sensitive fibers, substantiates the hypothesis that precisely these simultaneous lesions in both nerves have their basis in ischemia and, thus, are an expression of ischemic polyneuropathy.

The frequency of the prevalence implies that isolated lesions in one of the peripheral nerves of the upper extremity are far more frequent, perhaps as an expression of secondary lesions from damage to the locomotive system.

Etiopathogenesis of Neurological Damage

For the reasons stated above, we can only conclude that the development of neurological damage due to vibration is a consequence of multifactorial influences. Apart from the vascular component, a number of influences from damage to the skeleton and the soft parts of the upper extremities contribute secondarily to the damage of the peripheral nerves via irritation of the nerve stem. We rather associate this type of damage with heavy work itself, which easily involves overstress of the extremities. Closely connected with this are the influences of the material being machined, climatic influences, especially the influence of cold, and finally, the influence of skill.

The primary effect of the vibration itself cannot, in principle, be denied. If there exists a recognized direct effect on the vessels, one must also assume an effect on the other parts of the hand–arm system. However, it does seem to us that this primary effect of vibration stands somewhat in the background, behind all the other influences described.

HYGIENIC ASPECTS

From the hygienic point of view, among the many factors responsible for the adverse effects of hand-transmitted vibration, the physical characteristics of vibration itself, exposure time, and the so-called external factors are of maximum interest. The physical characteristics of vibration are discussed most often in the literature. But these physical characteristics very much depend on the type of vibration source, the properties of machined materials, and other working conditions on the one hand, and on the hand-arm-system position as well as the grip pressure and applied force on the other hand. The highest permissible values of vibration, as they are discussed below, are usually expressed in terms of some kinetic magnitude, most often in terms of root-mean-square (rms) values of vibration acceleration. Sometimes rms values of velocity or displacement amplitudes are used as well.

In our opinion, the choice of the particular magnitude of motion is not of decisive importance, because a third-octave or narrow-band spectra of these magnitudes are mutually convertible. Unfortunately, when using kinetic quantities in our standards, we are not able to estimate the most dangerous frequency regions, because the frequency course of vibration limits depends on the chosen quantity.

Some investigators, therefore, suggest the use of force values as limits of hand-transmitted vibrations. Unfortunately, the advantages are negligible in comparison with the complications which the force measurements would involve in common hygienic practice. Furthermore, vibratory force measurements alone cannot shed much more light on the problem of estimating the most critical frequency regions.

In view of these facts, it was logical that some authors suggest the measurement and evaluation of vibration energy transmitted to the human body. Internationally, this concept was presented by Dr. Lidstrom in 1972;[5] Razumov and other Soviet authors had published similar recommendations.[6] Unfortunately, Razumov later simplified the problem by assuming that velocity measurements can fully encompass energy transmission. The measurement and evaluation of vibration using transmitted energy as the quantity of choice has not yet been introduced because of inherent problems that would be even greater than those in vibratory force measurement.

In our attempts, vibration investigations were from the very onset based on vibration transmissibility measurement.[7] In epidemiological studies on the adverse effects of pneumatic tools,[8-11] we noticed that the effects of hand-transmitted vibration first occur in the less skilled worker. Next, we noticed that the skillful workers used smaller applied force and grip pressure (i.e., they did not grip the handle so firmly). Accordingly, we began to measure vibration transmission with respect to the grip pressure and applied force. In these laboratory measurements, we were able to prove the dependence of vibration transmission on the above-mentioned grip pressure and applied force and hand-arm posture. We also watched some of the less expressive resonances, the frequency position of which also changed with respect to the followed quantities.[10] In an effort to objectify our findings, we began to measure the hand-arm driving point mechanical impedance (Figure 1). In Figure 2 can be seen the measured spectra of hand-arm driving point mechanical impedance for the vertical direction of vibration. In the same figure, a mechanical model of the hand-arm and its parameters (see the table) are also shown. In the table, m is the effective mass, k the spring constant, and b the damping coefficient. As can be seen from the figure, we have not succeeded in estimating impedance values above 200 Hz. This happened because in this frequency region the measured data were influenced by the construction of the handle used in the experiments. This fact, as well as some other difficulties that had to be solved in the measurements, confirmed our opinion that this approach would prove too complicated for the routine hygienic measurements as they are made by the district hygienic stations in our country. In particular, energy measurements in the higher frequencies are difficult, and, as has often been reported in the literature, these frequencies are very often responsible for the adverse effects of applied vibration. The hand posture in measurements of hand-arm impedance in the

Figure 1. Mechanical impedance test apparatus.

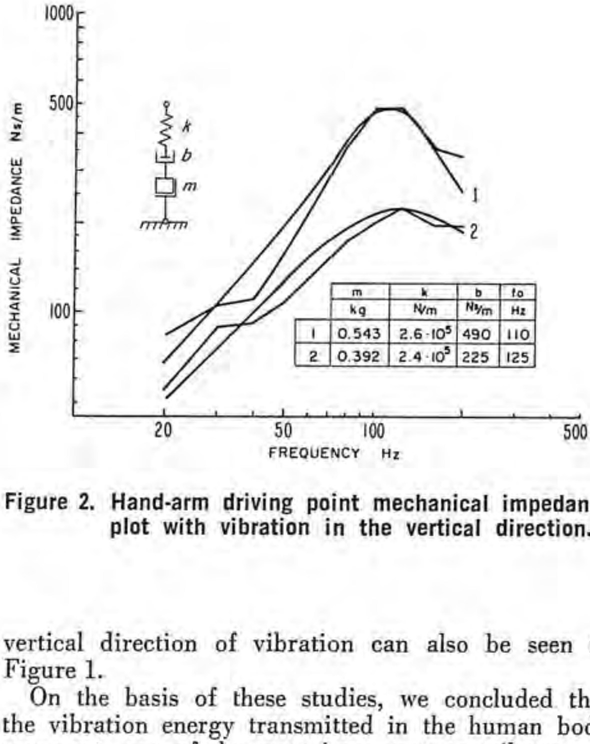

Figure 2. Hand-arm driving point mechanical impedance plot with vibration in the vertical direction.

vertical direction of vibration can also be seen in Figure 1.

On the basis of these studies, we concluded that the vibration energy transmitted in the human body represents one of the most important contributors to the adverse effects of vibration. This energy encompasses a greater complexity of these effects than do motion magnitude measures such as acceleration or velocity, because the influence of grip pressure and applied force as well as hand-arm position is partially taken into account. In view of this fact on the one hand and the complexity of vibration energy measurements on the other, we have suggested in the ISO document concerning hand-impedance measurements[12] a correction procedure that should be applied to the draft international standard on the limits of hand-transmitted vibrations. We believe that the application of our proposal would improve the present draft and would not complicate the measurement procedures. In our proposal, which is discussed in greater detail below, we assume wide international collaboration and data exchange.

Even in evaluating the influence of exposure time, we recommend that the energy concept be used. For this reason, we proposed the so-called "energetic mean" for characterization of variable vibration (i.e., variable vibration should not be characterized by arithmetic means). Consequently, we suggested a change in the time-correction schedule to correspond to the energy law.

On the other hand, we agree that the evaluation of regularly interrupted vibration should differ from the energy-law concept. Here it is assumed that the total daily dose can be raised a little if the vibration exposure is regularly interrupted by breaks without vibration. This assumption is based on the fact that the regeneration time after exposure depends on the second or third power of the exposure time period, (i.e., that regular breaks make it possible for the organism to tolerate this greater dose). This fact has only partially been experimentally confirmed.

It is evident from the data of regularly interrupted vibration exposure that by measuring and limiting the vibration energy transmitted to the human body we have not solved the entire complex problem of vibration limits and that the energy concept is only a temporary working hypothesis that will have to be changed or improved in the future, provided enough research data become available.

Hand-Transmitted Vibration Limits

The first hygienic standard containing hand-transmitted vibration limits known in our country was the Soviet Hygienic Regulation of 1955.[13] The limit contours stated in this standard can be seen in Figure 3

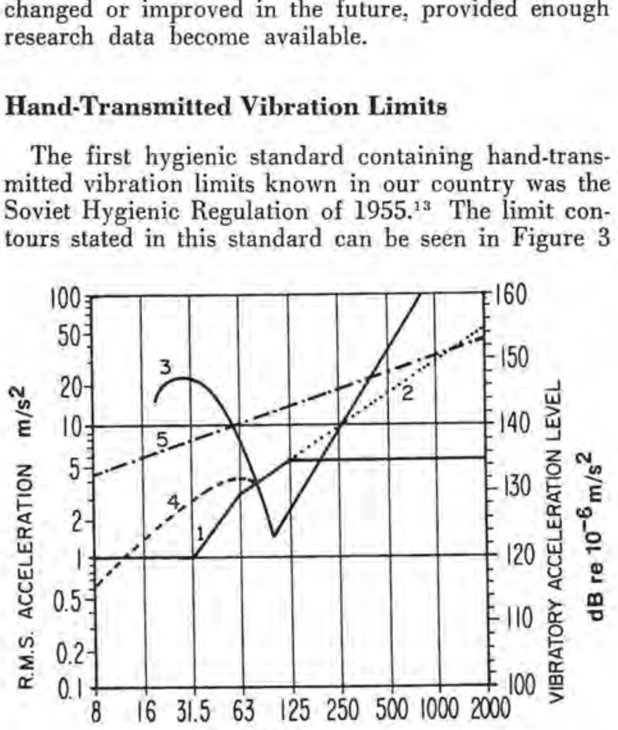

Figure 3. Vibration limit curves (see text).

(curve 3). According to this regulation, only the basic frequencies (e.g., the frequencies corresponding to motor rpm) were to be evaluated. The author of this regulation, the Soviet scientist Dr. Andreeva-Galanina, subsequently decreased the limit values in the range of lower frequencies[14] (curve 4), because she feared that bone and joint changes could occur on exposure to vibration (in the range of lower frequencies) that did not exceed the given limits. The corrected Andreeva-Galanina values were introduced into hygienic practice in our country as a preliminary method by Kryze.[15] In his thesis in 1966, Louda[7] proposed a limit curve (curve 2); this curve was based on vibration transmission and subjective perception measurements and on the published Soviet experimental data. The first Czechoslovakian national hygienic standard issued in 1967 was based on this curve even though Louda's curve was not accepted for the range of higher frequencies (see curve 1). The Czechoslovakian and Louda curves, together with the curves of Miwa[16] and other authors, were used in estimating the international limits given in the present ISO draft.[17]

It should be mentioned that subsequent USSR limits for hand-transmitted vibration differ to some extent from the ISO draft limits. The present Soviet standard encompasses the fact that the influence of force is partially taken into account; generally, it states that in measuring vibration the applied force should correspond to 80% of the maximal force exerted in the practical use of the tool. On the other hand, there are some difficulties in using this standard in the evaluation of a variety of hand-tool operational situations (e.g., as occur in the cutting of man-made jewels). The present Soviet limits represent a good compromise between the hygienic demands and mechanical-tool production possibilities; however, it is important to note that they are not hygienic limits in the strict meaning of this term. According to the opinions of our hygienists, bone and joint lesions can still occur even if these limits are not exceeded. Furthermore, some investigators object that the frequency contours of these limits differ from the human frequency response curves shape (perception or EMG curves, for example).

PROPOSAL OF A CORRECTION PROCEDURE TO THE PRESENT LIMITS STATED IN ISO DRAFT

Our experience indicates that the present ISO draft[17] does not make it possible to evaluate accurately vibration exposure situations that differ from typical conditions of operating mechanical tools. As an example of such an atypical situation, let us mention the transmission of vibration from the handle of a motorcycle. In this case, the transmission of vibration is less effective owing to the fact that the grip pressure and applied force values are near to zero. Consequently, we believe that the adverse effects of motorcycle vibration on the hands is not as serious as could be assumed from the given ISO limits. In some other cases, the opposite situation could occur, i.e., owing to the firmer coupling of the hand and handle, the adverse vibration effect would be underestimated.

In view of this, we propose the use of hand driving point impedance data as a basis for making necessary corrections. The correction value should be given by the ratio of the resistance measured for the hand coupling (imitating the particular vibration transmission situation) to the reference resistance. The corrections should lie in the range of ±20 dB, i.e., the correction factor should not be greater than 10 nor smaller than 0.1. In the aforementioned document,[12] the main principles of hand impedance measurement were also proposed.

The proposed correction procedure assumes that reference impedance data will be stated. The ISO/TC 108/SC 4 (WG 5) accepted this under the condition that the reference hand posture as well as the applied-force and grip-pressure values will be stated. The authors of this paper suggested a reference position of hand-arm, which was later accepted by working group 5[18] (see Figure 1). We hope that reference grip-pressure and applied force values will be ready for proposal soon, after the necessary measurements have been finished.

We believe that our proposal improves the present draft international standard by adding a table of corrections based on impedance data because the data will be obtained by measurements in various laboratories in the world under different measuring conditions. The common hygienic measurements would not become more complicated in this case.

Prevention

Preventive measures to limit the damaging effect of vibration are aimed at decreasing the vibration at the source, diminishing the transmission of vibration to man, limiting the inducing effect of cold, shortening the exposure time, and prescreening workers for work in vibration hazards.

The most effective but very difficult to solve are technical measures decreasing the extent of the vibration at the source. Organizational measures limiting the exposure time to vibration are effective. The effect of personal protective gloves for decreasing the transmission of vibration is doubtful, but they may decrease the unfavorable element of cold. Preventive and periodical medical examinations, which have the purpose of excluding persons sensitive to exposure by vibration, do not remove the hazard although they decrease somewhat the number of affected persons.

Technical Preventive Measures

Most of the diseases due to vibrations are, at present, developed in work with mechanical tools. Technical adaptations of mechanical tools that decrease the damaging effect of vibrations are generally considered to be the most effective measure for limiting the occurrence of occupational diseases due to vibrations.

The first technical solution was found in pneumatic tools where the unfavorable cooling effect of expanded air was removed by dispersing and suitably directing the exhaust air.

A rather important technical problem is the correct decision concerning the size and shape of the tool handle and its suitable coating. The correct solution of this problem is often underestimated; we often see handles that are too small and unsuitably shaped and thus, the position of the hand during work is unnatural. The cold metal surface of the handle increases the unfavorable cooling effect, and yet the small dimensions of the handle make it impossible to wear gloves.

About 15 years ago, the tool producers began to produce so-called antivibration handles. These handles are designed to be fixed to the tool body by means of rubber springs. Such handles decrease vibrations of more than 200 Hz effectively, but they usually do not influence vibrations of less than 100 Hz. Most of the pneumatic tools have significant maxima in the spectrum of acceleration at frequencies below 100 Hz, and thus, no significant decrease of the hazard was achieved. The reported subjective improvement is very often caused by better shaping, suitable dimensions, and better coating of these handles. In tools that vibrate intensively in the frequency region above 200 Hz, the effect of antivibration handles may be considerable.

An exhaustive analysis of the causes of intensive vibration in pneumatic tools concluded that the existing design affords the possibility of decreasing the vibrations only slightly by means of the mentioned elastic connection of the handles. A considerable decrease of vibration can, in this case, only be achieved if the tool design is changed. Recently designs have appeared in our country that considerably decrease the vibration of the tools with a straight motion of the piston.[19] This design also decreases the static effect during work.

Designs and technologies that isolate the operator from direct contact with the vibrating tools are very effective technical measures. Unfortunately, this type of mechanization cannot be universally applied.

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