CHANGES OCCURRING IN THE CARDIAC NERVOUS APPARATUS DUE TO THE ACTION OF ULTRA-HIGH-FREQUENCY FIELD

V. Yu. Pervushin

From the Laboratory of Prof. A. V. Triumfov, Corresponding Member of the USSR Acad. of Med. Sci. and the Department of Normal Anatomy (Research Director – Prof. V. M. Godinov), The S. M. Kirov, Order of Lenin, Academy of Military Medicine, Leningrad.

(Received December 4, 1956. Presented by Academician K. M. Bykov)

Exactly how the changes caused by the action of an ultra-high-frequency (UHF) field on the body are effected is still not clear. Some researchers believe that the changes occurring in the organs are caused by the specific action of the UHF field itself, while others believe that they are caused by the diathermic effect of this factor. The role played by the nervous system in the pathological reactions which arise in the organs due to the action of the UHF field has not been explained. The available data from morphological studies do not well support the physiological facts known concerning this subject.

As an example, we cite the studies which have been made regarding the effect of UHF waves on the heart. From the works of N. V. Tyagina (1957), the action of these waves is known to cause serious changes in cardiac activity. Long exposure to a UHF field is attended by structural changes in the myocardium [10]. It is possible that these structural changes of the myocardium cause functional disturbances in the activity of the organ. With equal basis, one could propose that these disturbances are caused by changes in the nervous apparatus of the heart, which has great influence on the functional regulation of the organ. However, this important problem has not yet been resolved. In general, there are only a few works which study the morphological changes occurring in the nervous system under the influence of the UHF field, and nothing is known about the effect of the UHF field on the peripheral parts of the nervous system.

The above-mentioned was our reason for studying the condition of the cardiac nervous apparatus in animals subjected to the general action of a UHF field. We examined the nerve centers participating in innervation of the heart and the innervated substrate – the myocardium – as well as the intraorganic nervous apparatus.

From the works of E. K. Plechkova [12] and of A. Ya. Khaborova [13], it is known that the cardiac receptors consist of the endings of neurons whose bodies are located in the nodose ganglia of the vagus nerve and in the upper thoracic spinal ganglia (Th_1 - Th_5). Sympathetic innervation of the heart is realized through the nerve cells of the lateral nucleus of the intermediate zone of the eighth cervical and the first two thoracic segments of the spinal cord (central neurons) and by the cells of the sympathetic cervical ganglia (peripheral neurons). Parasympathetic innervation of the heart is represented by the cells of the dorsal nucleus of the vagus nerve in the medulla oblongata, branches of which cells terminate in pericellular apparatuses on the neurons of the cardiac ganglia.

EXPERIMENTAL METHODS

All these formations were examined. The medulla oblongata, the spinal cord, and the ganglia of the spinal cord, the sympathetic trunks and the vagus nerves were stained by Nissl's method (alcohol fixation with celloidin imbedding). In order to examine the intraorganic nervous apparatus of the heart, pieces of the heart were fixed in 12% neutral formalin and then impregnated with silver by the Bielschowsky-Gross method.

The myocardial sections were stained with hematoxylin-eosin, for fat, and according to Heidenhain.

The first experiments were done on four male cats, which were subjected to the general action of a UHF field for 2 to 10 hours (for 2 hours a day).*. The body temperature was observed to rise in the two animals which had been exposed to the action of a UHF field with a current density of 0.03 w / cm^2 in power during the experiment; in two other cats, a less intense influence of the field (with a current density of 0.005-0.01 w / cm^2 in power) did not cause a hyperthermic condition. The animals were sacrificed 72 hours after the end of the experiment.

EXPERIMENTAL RESULTS

Examination of the preparations showed that some components of the intraorganic cardiac nervous apparatus had undergone serious changes. This was particularly true of the myelinated fibers and the sensory endings.

Although a certain number of unchanged myelinated fibers were found, a rather large number of changed ones were also observed. The most frequent manifestations of change were coarsening and increased impregnation of the fiber, bulges and neuroplasmic incrustations on it. Such fibers lost their usual structure. The axon, medullary sheath and neurilemma – the components of a normal fiber – became indistinguishable, and the entire fiber stained diffusely with silver to an intense black.

Such a picture is not specific for the action of a UHF field. Similar pictures were observed by B. I. Lavrentyev [8], D. N. Vyropaev [1], V. F. Lashkov [10] and V. V. Kupriyanov [5] on pathological material, found by B. A. Dolgo-Saburov [2] and V. V. Kupriyanov [4] in experiments with oxygen starvation and experimental uremia [6], and observed after the action of roentgen rays on the body [7].

In some fibers, intensely impregnated portions alternated with weakly impregnated portions. Such fibers had uneven, bulging contours, and very often those sections where the impregnation was poorly absorbed were the most swollen. This type of change is illustrated in Fig. 1. V. V. Kupriyanov mentions similar changes when describing the results of experiments with oxygen starvation.

The most profound changes appeared in the preterminal sections of the receptor fibers. As Fig. 1 shows, it was there that the most pronounced bulges and neuroplasmic incrustations were observed and that "myelin balls" appeared, evidently caused by the rupture of the neurilemma. The changes observed confirm the view of B. A. Dolgo-Saburov and V. V. Kupriyanov that the preterminal sections are the most "woundable" parts of the peripheral branch of an afferent neuron.

In contrast to the myelinated fibers, most of the nonmyelinated fibers retained their normal structure.

Profound changes were also observed in the sensory endings. As is known, there are two main types of cardiac receptors: receptors with constricted arborization, which are characterized by the concentration of the receptive substance, and diffuse receptors with wide-spread branches. According to the data of A. Ya. Khabarova, the first type is made up of the endings of vagus nerve sensory fibers, while the second belongs to the afferent neurons of the spinal ganglia.

Although a certain number of the sensory endings remained intact, many of the receptors examined were changed. Sharp changes in the preterminal sections, i.e., heightened argentophilia, and the breaking off of the reticula the "little rings" and the "little knobs" from the branches of the receptor fibers, pointed to the occurrence of irreversible degenerative processes in some of the cardiac sensory nerve endings (Fig. 2). Such changed endings were found in all layers of the organ's wall.

Both types of receptors were changed in all four of the experimental animals, so that it was impossible to say that one type of receptor was more "woundable" than the other; some sensory endings, however, changed in a different way from other sensory endings. In the receptors with the concentrated receptive substance, the

* The experiments were done on male cats in order to exclude the changes which B. A. Dolgo-Saburov [3] observed in the cardiac nervous apparatus of female cats during pregnancy.

preterminal sections stained an intense black with silver, became swollen and formed varicosities and neoplasmic incrustations. The receptor fiber terminals were also extremely argentophilic. Some of the receptor end structures kept their connections with the terminals, while others lost it (see Fig. 2).

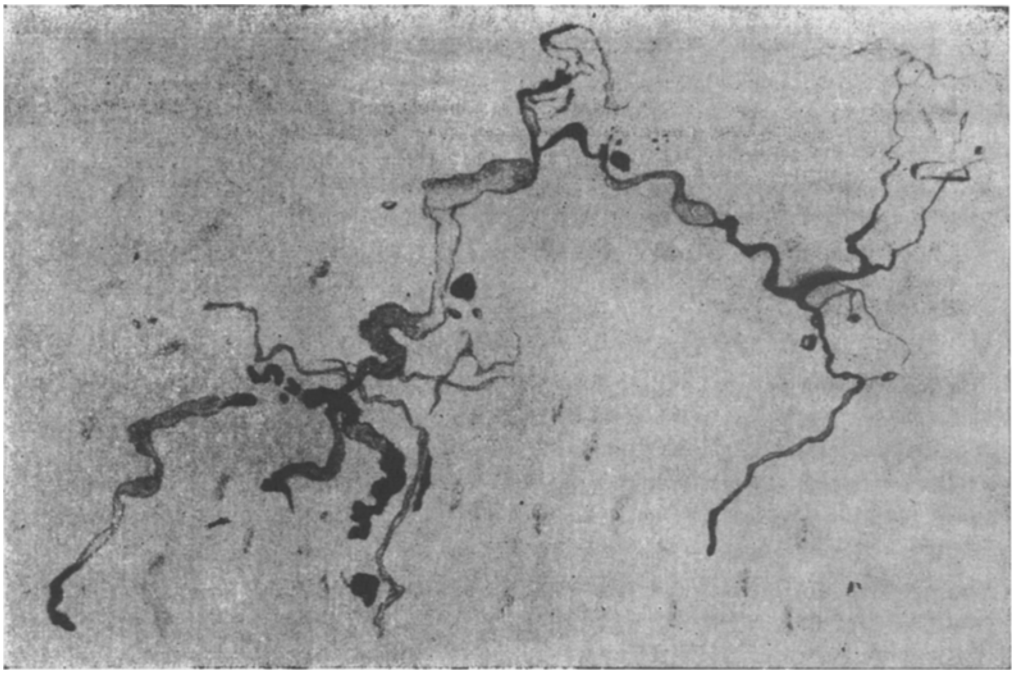

Figure 1. Changes in the preterminal sections of the receptor fibers in the wall of the left auricle of a cat. Intense action of the UHF field for 10 hours. Magnif. ocular 15x, objective 40 x. Impregnation by Bielschowsky-Gross method.

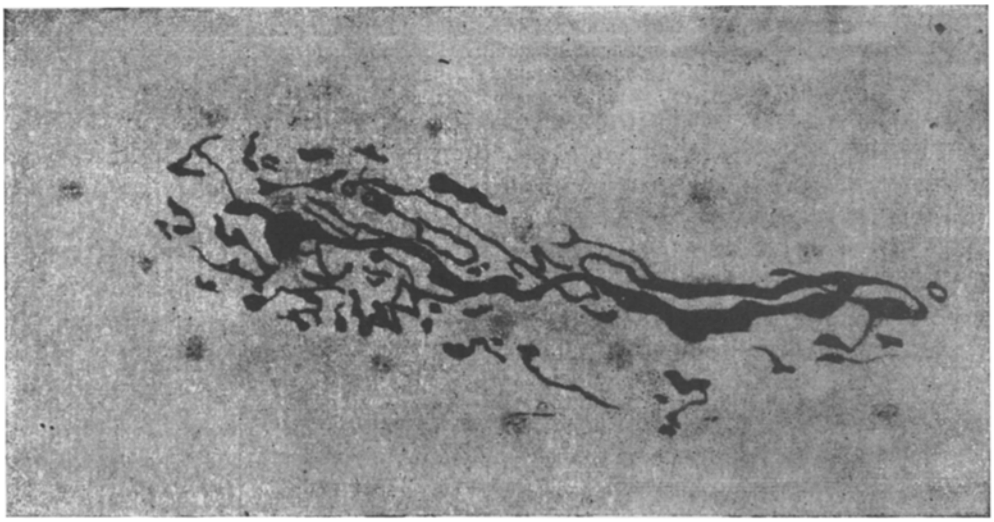

Figure 2.
Degeneration of a receptor with constricted type of branching in the wall of a cat's right auricle. Intense action of the UHF field for 2 hours. Magnif. ocular 15 x, objective 40 x. Impregnation by Bielschowsky-Gross method.

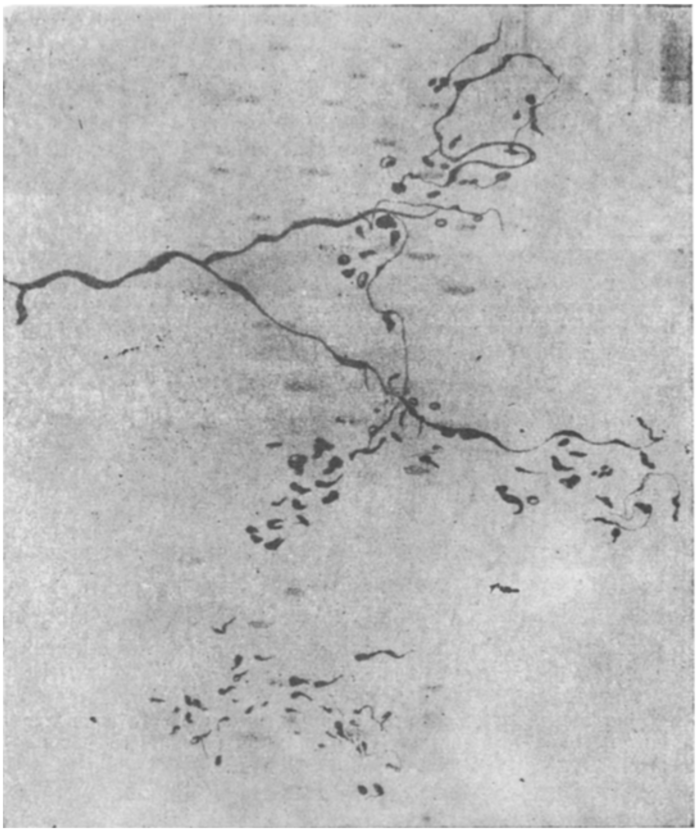

Figure 3.
Destruction of a Receptor with diffuse type of branching in the wall of a cat's right auricle. Intense action of the UHF field for 10 hours. Magnif. ocular 15 x, objective 40 x. Impregnation by Bielschowsky-Gross method.

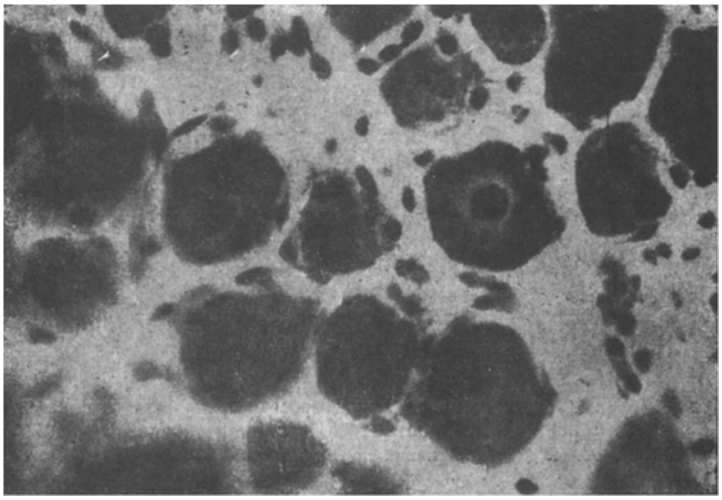

Figure 4.
Group of irreversibly changed nerve cells of spinal cord ganglia (Th_1) of a cat. Intense action of the UHF field for 10 hours. Photomicrograph. Nissl's stain. Magnif. ocular 15 x, objective 40 x.

Figure 3 shows a more or less typical view of a changed receptor with the diffuse type of branching. Heightened argentophilia was also observed here, although no neuroplasmic incrustations nor swelling of the receptor fiber or its terminals could be seen. The destructive processes are the most evident – the breaking off of the terminal structures and the disintegration of the whole length of the sensory ending. This heterogeneity in the change pictures existing in the different types of receptors is explained, we believe, by the difference in the amount of receptive substance contained in the sensory endings with the diffuse type and in those with the constricted type of arborization.

The next thing which interested us was the condition of the nerve cells in the ganglia of the heart and their pericellular apparatuses. A large majority of the nerve cells looked as usual, and only very rarely did one find single elements with signs of reactive changes. Slight changes were also observed in the pericellular apparatuses. The changes consisted in the heightened argentophilia and occasionally in the swelling of the pericellular apparatuses. These pictures seem identical with those which B. I. Lavrentyev [9] observed in a live frog's heart which had been subjected to the action of UHF waves.

No substanital pathological change was observed when the condition of the cardiac muscle was examined.* The muscular tissue was normal, and slight changes, which can frequently be found in practically healthy animals, were found on a small piece from only one animal.

Therefore, examination of the heart showed that individual elements of its nervous apparatus (myelinated fibers, receptors, pericellular structures) became changed, sometimes very greatly. These changes were evidently partly reversible and partly irreversible. However, the UHF field intensity which we used did not cause noticeable structural deviations from the normal in the substrate innervated by the nervous apparatus.

The next section of this work will examine the extraorganic nerve centers which participate in the innervation of the heart. After finding changes in the nervous apparatus of the organ, one would expect to find changes in the sensory cells of the spinal ganglia and of the vagus nerve ganglia. And, in actuality, among the cells of the spinal-cord ganglia, we did find some which were changed. However, one must point out immediately that there were not many of these changed specimens; the majority of the cells had a normal nucleic and cytoplasmic structure.

The changes in the sensory cells of the spinal ganglia were for the most part reversible and were mainly concerned with the chromatophilic matter – redistribution of its granules and partial chromatolysis. More profound changes in the cell structure indicating the death of the neuron were less often found. This was observed in the two animals which had been subjected to the more intense action of the UHF field. Figure 4 shows a group of the cells. The nuclei of two cells are intensely stained; the chromatophilic matter has lost its usual granular structure, and chromatolysis has occurred in the region of the perikaryon. There was no doubt that the change in these neurons was irreversible.

A completely different picture was found upon examination of the sections from the nodose ganglia of the vagus nerve; the only reaction changes observed were slight structural displacements of the chromatophilic matter in individual cells. Nor were changes found in the sympathetic cervical ganglia or in the dorsal nucleus of the vagus nerve in the medulla oblongata. Only the cells of the spinal cord were further affected by the action of the UHF field. In one cat, a diffuse and thorough staining of the dendrites was observed in some cells, and the axon was beginning to stain thoroughly. In the posterior horns, separate cells stained intensely and had angular contours. The dense staining extended quite a distance along their branches. In another animal, an infiltration of the brain tissue by elements of the blood was observed in the intermediate zone. In these cats, single cells with signs of irreversible changes were also found in the intermediate zone of the spinal cord.

Therefore, the experiments conducted showed that the action of a UHF field of a definite intensity first causes changes in the afferent neurons. In the vegetative innervation centers of the heart and in its peripheral components, there is either only very slight change or none at all.

Besides the material described, sectional material from two dogs which had been subjected to the action of a UHF field in the experiments of N. V. Tyagin for many months (two hours daily with a current density of 0.005-0.01 w / cm^2 in power) was at our disposal.

There were no changes observed in the cardiac nervous apparatus of these animals. Although a large number of receptors were examined, no changed forms were found. Small varicosities and sometimes the

* The myocardial preparations were kindly examined by D. S. Sarkisov, Doctor of Medical Sciences.

heterogeneous impregnation of axons could be observed. There was a remarkable development of the connective tissue in the ganglia. In addition, various cell elements in the spinal ganglia and in the nodose ganglia of the vagus nerves showed signs of death – residual nodes of Nagcotte and single "empty" capsules, some filled with blood elements. The cells of the spinal cord were also changed. We observed changed cells most frequently in the lateral nucleus of the intermediate zone, in the Clarke-Stilling columns and in the posterior horn's own nucleus. Some of the cells in these nuclei had thoroughly stained interstices and perinuclear or marginal hyperchromatosis. The nerve cells retained their normal structure in the medulla oblongata and in the sympathetic cervical ganglia.

We should like to point out two aspects of the picture – the fact that a considerable number of cardiac receptors were intact and that residual nodes were present in the ganglia of the vagus nerves and in the spinal ganglia. These facts are in complete accord with the data presented above. Therefore, in the first place, the changes found in the receptors of the first four animals, i.e., the cats, did not lead to the degeneration of all the sensory endings. The majority of them were retained and became definitely adapted to chronic UHF field influence. In the second place, the degeneration of the receptors, or nerve cell endings, did not always imply the death of the nerve cell to which they were attached. New receptors were formed by regenerative processes occurring in the preserved portions of the neurons. Some of the neurons, however, did die, which was shown by the degeneration of the receptors after the 2-10 hour exposure, the irreversibly changed nerve cells in the ganglia of the spinal cord and of the vagus nerves in these same animals and by the fact that chronic exposure caused the appearance of residual nodes in the respective ganglia. All this shows that the afferent neurons are extremely sensitive to the action of high frequency waves.

It was interesting to compare the morphological data which we have presented with data from experimental clinical studies on the effect of the UHF field on cardiac activity. N. V. Tyagin observed bradycardia, changes in the S-T interval and a thickening of the descending slope of the R wave after intense exposure of the animals (dogs). With chronic intense action of a UHF field, the above electrocardiographic changes disappeared, and adaptation phenomena were observed. This data was obtained by N. V. Tyagin from experiments made on the two dogs already mentioned in this work, material from which we examined.

Involuntarily, an analogy arises with the results of the morphological studies. Structural changes of the cardiac nervous apparatus occurred in the animals which had been given a comparatively small dose of exposure (0.005-0.01 w/cm^2), but there were no definite indications of change in the nervous apparatus of those dogs in which adaptation to UHF field action was observed. The structural changes caused by the action of the UHF field may possibly bring about the functional shifts which N. V. Tyagin described in the operation of the heart.

Naturally, the question of why these changes occur arises – are they the result of general hyperthermia? Our data does not give a definite answer. However, one must remember that two out of the four cats were exposed to the UHF field action at a distance far enough from the emanation source to preclude the occurrence of a hyperthermic condition , and that changes nervertheless occurred in these animals, in both the cardiac receptors and separate cells of the spinal ganglia. One can therefore propose that the structural changes in the nerve tissue are caused by more than general hyperpyrexia of the body.

Analyzing the changes caused in the body by the action of a high frequency field, A. V. Lebedinsky [11] suggested that some of these changes could be explained by the stimulation of the afferent nerves.

The comparative lack of material makes any more definite conclusion impossible. One can, however, conclude that the changes occurring in the peripheral parts of the nervous system, and particularly in its afferent elements, must be taken into account when studying the effect of a UHF field on the body. It may be that some of the pathological reactions taking place in the body are not primary, and are not caused directly by UHF field action, but by the changes in the afferent links of many reflex arcs.

I. P. Pavlov's principle that dynamics adapt to structure is especially important when the organ or tissue is subject to change. In this case, basic data can only be obtained by simultaneous examination of structure and function. Further investigation of the effect of a UHF field on the body should therefore be done by physiologists and morphologists working in close conjunction. Such a study would give a balanced and three-dimensional idea of the processes which this factor causes in the body.

SUMMARY

The afferent neurons of the heart were the first to be affected in cats subjected to the action of ultra-high-frequency field from 2 to 10 hours. The receptor fibers of sensory endings, mainly the preterminal sections were most severely damaged. Altered nerve cells were seen in the spinal cord ganglia (Th_1 - Th_3) and vagal nerve ganglia. No alterations were noted in the vegetative centers of the heart.

The assumption of an intense sensitivity of the afferent neurons to the chronic effect of the ultra-high-frequency field has thus been confirmed.

LITERATURE CITED

[1] Vyropaev D. N., The Morphological Study of the Sensory Innervation of Internal Organs (in Russian), Moscow, 1948, pp. 70-83.

[2] Dolgo-Saburov B. A., The Reaction of Vein-Wall Receptors to Changed Conditions of Body Subsistence (in Russian), Vrachebnoe Delo, No. 10, 1950, pp. 1-9.

[3] Dolgo-Saburov B. A., Arkh. Anat. Gistol. i Embriol., 1952, No. 4, pp. 8-23.

[4] Kupriyanov V. V., Arkhiv. Patol., 1953, Vol IV, No. 2, pp. 15-24.

[5] Kupriyanov V. V., The Innervation of the Lesser Circulatory System Vessels (in Russian), Author's Abstract of Dissertation, Leningrad, 1954.

[6] Kupriyanov V. V., Data on The Experimental Morphology of Vascular Receptors (in Russian), Leningrad, 1955.

[7] Kupriyanov V. V., in Tridy Voenno.-Morsk. Med. Akad., Leningrad, 1956, Vol. 54, pp. 45-60.

[8] Lavrentyev B. L, in the book: The Morphology of the Autonomic Nervous System (in Russian), Moscow, 1946, pp. 13-83.

[9] Lavrentyev B. L, Fedorov B. G., Tridy Vsesoyuz, Inst. Eksptl. Med. No. 8-9, 1934, pp. 6-7.

[10] Lashkov V. F., in the book: The Morphology of the Sensory Innervation of Internal Organs (in Russian), Moscow, 1948, pp. 207-227.

[11] Lebedinsky A. V., in the book: Questions on the Usage of Short and Ultra-Short Waves in Medicine (in Russian), Moscow-Leningrad, 1940, pp. 121-129.

[12] Plechkova E. K., in the book: The Morphology of the Sensory Innervation of Internal Organs (in Russian), Moscow, 1948, pp. 46-69.

[13] Khabarova A. Ya., Doklady Akad. Nauk SSSR, 1955, Vol. 105, No. 1, pp. 188-192.