AN ELECTROPHYSIOLOGICAL INVESTIGATION OF THE RECEPTORS IN THE JOINT CAPSULE*

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The afferent impulses which arrive at the central nervous system from the joints play an important role in the complicated perception and motor activities of animals and man.

Boyd and Roberts [5] and Scoglund [12] described changes in the character of the afferent signals, from nerves of the knee joint in the cat associated with movement of the endings in different ways. It is known that the capsule of the cat's knee joint is richly innervated [1, 2, 3, 10, 11 et al]; however, up to the present we have not learned what types of stimuli are perceived by the receptors located in the joints, and thus, what form of signals are sent to the central nervous system from the numerous joints during various states of the organism.

For the resolution of this question we selected the knee joint of the cat, which, in its structure and blood supply, is close to the knee joint of man [4, 6, 7].

EXPERIMENTAL

The cats were placed under nembutal narcosis, and then the knee joint capsule was exposed and its nerves prepared. The biopotentials of the joint nerves during stimulation of the knee capsule's receptors were recorded through an alternating current amplifier (frequency band 5–1500 hertz) on a cathode oscillograph. Various forms of experiments were performed on the 30 cats. The results of the investigations were premanently recorded on 707 photographs. Following the completion of the experiment, the knee joint capsule was transferred to a histological laboratory, where, following appropriate treatment, its innervation was studied [3]. This made it possible to form a sufficiently complete concept of the innervation of the capsule and its receptor apparatus. In a series of experiments we were able to establish a connection between the character of the impulses and the type of receptor.

The posterior joint nerve consisted of 120-180 nerve fibers, and the middle joint nerve, innervating the anterior surface of the capsule, from 110-140 fibers. Both of them branched extensively in the joint capsule, especially the former, and terminated in nerve endings of various forms– free and encapsulated (Pacinian and Ruffinian corpuscles).

Efferent impulsation to these nerves was excluded by transection of the large nerve trunks in which the fibers of the joint nerves course. The biopotentials were tapped from fine branches, consisting of 50-70 fibers, and sometimes from even finer ones, in the order of 20-30 fibers.

In association with tactile stimulation of the capsule surface (20-200 mg) and with pressure of varying intensity (from 1.5 to 10 grams) impulses arose in the nerves of varied amplitude and frequency. Under the same simple conditions, the more intensive the pressure was, the greater the frequency. Along with an increase in the frequency of the impulses, they became less uniform in their amplitude. With tactile stimulation, low voltage impulses, in the range of 10-12 μv, were the most frequently seen. Since the density of distribution of the receptors was not uniform in the different areas of the capsule, in order to obtain comparable material we stimulated the very same point in the

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capsule with varying intensity. In this manner we established a different sensitivity to the applied stimuli for definite portions of the capsule. It was found that the posterior surface of the capsule was considerably more sensitive than the anterior.

In Fig. 1 it can be seen that impulsation appears in the posterior joint nerve when the surface of the capsule is touched. In the next oscillogram (Fig. 1b) there is a gradual change in impulsation in the posterior joint nerve under

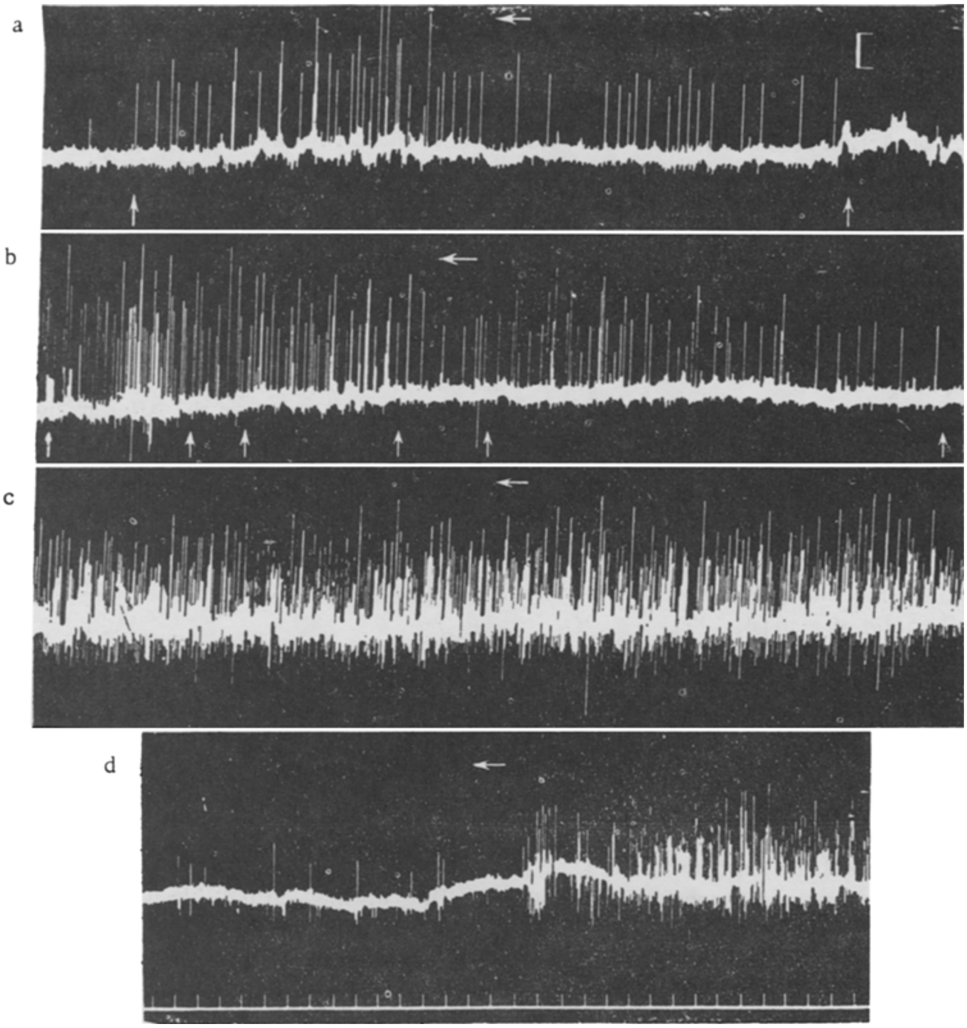

Fig. 1. Impulsation in the posterior joint nerve during tactile nociceptive stimulation of the capsule surface. a) Touch; b) touch, light pressure, strong pressure; c) prick; d) cessation of pricking. Below – time markings (1/50 of a second). Arrows indicate beginning and end of stimulation.

the influence of an increasing stimulus strength: the stronger the pressure, the more frequent the electrical impulses and the more varied their character. In Fig. 2 we see a change in the frequency of impulses with varying amplitudes when a different intensity of tactile stimulation is applied, and at the highest frequency the impulses are of the order of 10-12 μv.

In certain cases, with stimulation of definite portions of the capsule by sufficiently intense pressure, waves of high amplitude potentials appeared in the posterior joint nerve (36-42 μv), quickly adapting. Under histological investigation these portions of the capsule held encapsulated receptors – Pacinian corpuscles. We propose that these high voltage impulses belong to the Pacinian corpuscles, which are stimulated by significant deformation of the capsule.

This type of receptor was only present in the capsule in very limited numbers– from 3 to 5 [3, 6, 7, 12]. The impulses,described by Gray and Matthews,from the Pacinian corpuscles located in the tendinous sheath of the cat's foot were also of high amplitude and adapted rapidly.

Tactile sensitivity was present throughout the entire surface of the capsule, but the posterior surface was considerably more sensitive than the anterior, the latter having areas which responded only to a sufficiently intense pressure.

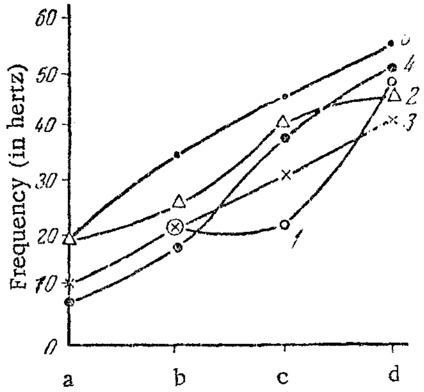

Fig. 2. Change in the frequency of impulses with different tactile stimulus intensity. a) At rest; b) touch; c) light pressure; d) strong pressure; 1) 36-42 μv; 2) 24-30 μv; 3) 18 μv; 4) 14 μv; 5) 10-12 μv.

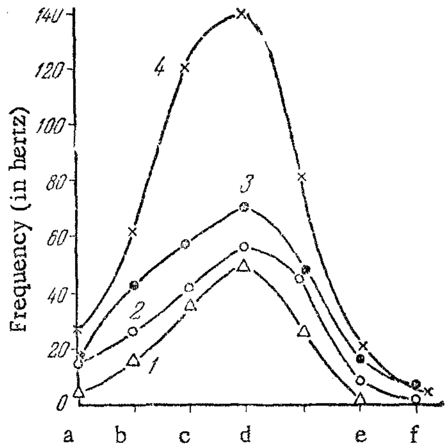

Fig. 3. Change in the frequency of impulses with pricking. a) At rest; b) touch with needle; c) beginning of pricking; d) pricking; e) 1.2 seconds after pricking; f) 2.3 seconds after pricking; g) 3.2 seconds after pricking; 1) 30 μv; 2) 10-12 μv; 3) 15 μv; 4) 18-24 μv.

Up until now it has remained unknown whether there are special pain receptors or whether any receptor sends pain signals under intense stimulation. We set up a series of experiments, which, to a certain degree, would answer that question. For the nociceptive stimuli we used pricking and piercing of the capsule, as well as chemical and thermal burning of its surface. Pricking the capsule with a needle in any area always caused an intense, but short termed, impulsation in the nerve. The oscillogram (Fig. 1b) obtained with this form of stimulation is characterized by impulsation of the most varied amplitude, among which,impulses of 18-24 μv are discharged with the highest frequency, attaining 160 hertz in certain cases. Thus, no specific impulsation was observed during this kind of stimulation; all that was noted was a considerably higher frequency impulsation in comparison with the response to tactile stimulation. Impulsation arising in the nerve when the capsule was pricked rapidly showed rapid extinction following cessation of the stimulation (Fig. 1d), and after 2-3 seconds either disappeared or was of the same frequency as before stimulation.

In Fig. 3 it is shown how the impulse frequency increased with change in the stimulation from tactile to nociceptive. Here it is also clearly seen that the 18-24 μv impulses possessed the highest frequency, and that with termination of the stimulation the frequency of all the impulses rapidly fell. A short term impulsation appeared when the capsule was pierced, which immediately ceased when the needle passed into the joint cavity. The needle could be retained in this position for a prolonged period of time without causing any impulsation in the nerve.

Local thermal and chemical burning of the capsule surface (in the first case– with a heated glass rod, in the second– with drops of turpentine) caused the appearance of a discharge of impulses in the nerve (Fig. 4a). In order to obtain a clear concept of the character of the impulses associated with these nociceptive stimuli,we first applied a tactile stimulation and then, in the very same place, introduced the nociceptive stimulus. With the latter, the frequency of impulses was always considerably greater than with touch and pressure. All of the types of impulses which were observed with the tactile stimuli appeared with the nociceptive as well, in addition to which we also recorded high voltage impulses of 45-55 μv.

Injection of a small amount (0.3 ml) of a harmful substance into the cavity of the capsule – HCl (20%), turpentine, hot Ringer's solution (56°) – caused a comparable short term impulsation. In these cases, just as with simple nociceptive stimulation, 18-24 μv impulses were disharged with the highest frequency.

Thus, we did not observe any special specific impulses inherent only in the response to nociceptive stimulation. However, the maximal increase in the frequency of impulses was absolutely clearly seen in the range of 18-24 μv.

a

b

c

d

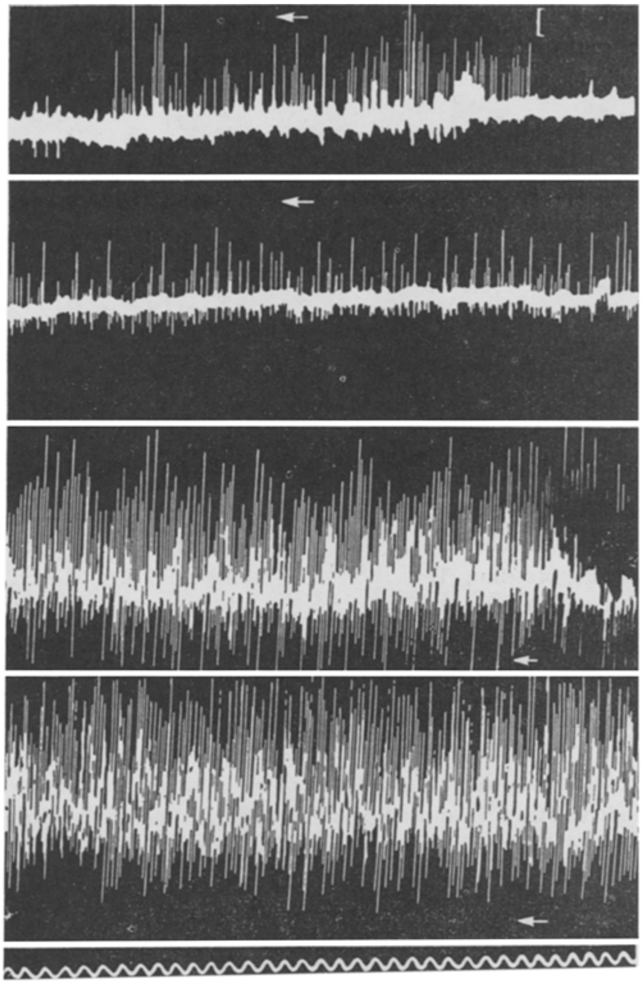

Fig. 4. Impulsation in the posterior joint nerve with nociceptive stimulation of the capsule. a) Local burning of the capsule; b) injection of air into the cavity of the capsule (3 cm^3); c) injection of cold Ringer's solution (4°) into the cavity of the capsule (3 cm^3); d) injection of heated Ringer's solution (56°) into the cavity of the capsule (3 cm^3). Below – time markings (1/50 of a second).

It is difficult to say which group of receptors is responsible for this impulsation, since throughout the entire surface of the capsule there are various types of nerve endings in the form of small rings, knobs, and free fiber endings.

Many authors [9, 13, etc.) consider that the free nerve endings are the pain receptors: they terminate in the tissue and supply the fine vessels, which are also regarded as sources of painful sensations.

In the knee joint capsule there are a large number of free nerve endings, with an especially large number of them in the posterior portion of the capsule. In this area they lie closely applied to the vessels.

All the nociceptive stimuli used by us caused a short term impulsation, which immediately ceased upon removal of the stimulus. Thus, prolonged perception of pain, which arises with this class of stimuli, apparently does not depend on the action of coursing afferent impulses to the thalamus and the cortical centers, but rather on the prolonged retention of traces of the excitation in these centers. We encountered proof that the application of these nociceptive stimuli was painful for the cat: in those cases where one of the large nerve trunks, containing fibers which form the joint nerve, was not transected, when the nociceptive stimuli were applied a motor reaction arose in the cat and respiration markedly increased in frequency. With application of tactile stimuli of the most varied intensity this reaction never occurred. Gardner and Jacobs described a number of reflex vegetative reactions of the same kind in association with strong electrical stimulation of the nerves in the knee joint.

We performed another series of experiments in order to make more specific the difference between the character and type of afferent impulsation in the case of pressure and nociceptive stimulation.

When the joint is moved the capsule is stretched, which causes stimulation of the receptors within its walls. We decided to cause an artificial stretching of the capsule by injecting air into its cavity (3 cm^3).

In order to add nociceptive impulses to the impulses signalling the stretching of the capsule, we injected hot (56°) or cold (4°) Ringer's solution into the joint cavity in the same quantity as the air.

We made continuous photographs of the oscillations in the nerve during the entire period that the stimuli were being injected into the joint cavity, as well as 3-15 minutes afterward, thus making it possible to obtain an impression of the character of impulsation in these cases. The injection of air causes a small increase in the frequency of the electrical impulses even with maximal stretching of the capsule (4 cm^3); their frequency never exceeded 70 hertz. The oscillogram (Fig. 4b) shows the greatest increase in frequency in the impulses of 10-12 and 18-24 μv; high voltage impulses (30-35-42 μv) followed, not changing their frequency.

With the introduction of cold or hot Ringer's solution the impulsation changed markedly. As the stimulus entered the joint cavity the impulsation frequency increased proportionately; with the cold stimulus (Fig. 4c) it attained 370 hertz, while with heat– 410 hertz (Fig. 4d). Analysis of the oscillogram showed that both with cold and heat stimulation the frequency of the impulses in the 18-24 μv range was highest. Stimulation of the receptors in the capsule with high temperature immediately led to an increase in the frequency of the impulses in the 18-24 μv range up to 100 hertz; then, with the introduction of up to 1 ml of the indicated solution, a reduction in the frequency of the impulses occurred, down to 70 hertz. With further injection the frequency once again increased to 130-150 hertz.

The frequency of the impulses increased in proportion to the amount of the cold stimulus injected, and the impulses in the 18–24 μv range increased in frequency up to 100 hertz. Along with this, the high voltage impulses, in the ranges 30-36 and 42-48 μv, also always increased in frequency when nociceptive stimuli were applied. Thus, we noted a striking difference in impulsation with stretching of the capsule by indiffrent and injurious stimuli. We cannot say whether or not these impulses are a reflection of the impulsation from specialized receptors, but it is doubtless that thermal stimuli caused a special impulsation to the central nervous system.

When the injection of Ringer's solution of different temperatures was stopped, the impulsation decreased, still retaining a high frequency in the order of 80-90 hertz for the low voltage impulses which signal a deformation of the capsule. The high voltage impulses decreased in frequency 3 minutes after the injection by a factor of approximately 2, and, after 15 minutes, by an even greater amount.

The thermal stimuli caused a generalized tremor in the cats, which lasted several minutes after their application.

All the large nerve trunks supplying fibers to the composition of the joint nerves were transected, and it must thus be postulated that in this case the transmission was realized via the amyelinated nerve fibers that weave about the vessels.

Our investigation showed that the joint capsule has a high sensitivity to a diverse group of stimuli. The receptors located in it accomplish the most varied signal patterns for transmission to the central nervous system. This must be taken into consideration when studying the complex reflex reactions of animals.

SUMMARY

The character of the afferent impulsation was studied in the knee joint nerves of a cat during various stimulations of the joint capsule surface. Numerous oscillograms thus obtained have demonstrated the presence of receptors

of the tactile, temperature and nociceptive stimulations. Under equal conditions the stronger the tactile stimulation – the more intensive the impulsation in the joint nerve. The nociceptive stimulations provoked a rapid appearance of impulse discharges in the nerves which disappeared immediately after elimination of the stimulation. Stretching the capsule by administration of 4 ml of air, hot (+56°C) or cold (+4°C) Ringer's solution into the joint cavity caused prolonged impulsation to appear in the nerve, varying in character in each individual case. 10-12 μv impulses prevailed in tactile stimulations, and 18-24 μv in nociceptive, while during stretching of the capsule with hot or cold fluid numerous high voltage impulses were noted, –as high as 30-42-48 μv. Thus, different stimuli caused the transmission of different information to the central nervous system.

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