ANALYSIS OF THE STIMULATING EFFECT OF A HALF-WAVE AND FULL-WAVE RECTIFIED CURRENT OF VARYING FREQUENCY

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The use of currents of different shape and frequency for electrodiagnosis and electrostimulation requires a study of the mechanism of the stimulating effect. The few data in the literature on this problem are extremely contradictory: some authors consider that a half-wave rectified current has a greater stimulating effect than an alternating current [5, 6], others arrive at the opposite conclusion [1, 4, 7].

We made a detailed analysis of the stimulating effect of a pulsed rectified current, comparing its action under various conditions with the effect of such well-known stimuli as direct and alternating currents of different frequencies.

EXPERIMENTAL METHODS

The experiments were performed mainly on preparations of the sciatic nerve and shin and foot muscles of the frog. Some experiments were set up on plantar preparations, others with stimulation of the sciatic nerve of the frog through the skin.

An alternating current with a frequency from 20 to 20,000 cps was produced by a three G-2-A generator. Half- or full-wave rectification was achieved by passing the alternating current through appropriate semiconductor devices. The shape, amplitude, and direction of current were monitored by a cathode oscillograph.

The nerve was stimulated through silver or unpolarized Du Bois-Reymond electrodes. The basic uniformity of the results obtained by both electrodes and the data of the control experiments do not give grounds to relate the difference in thresholds between the alternating current and rectified current with the gross "physical" polarization which the latter could have caused.

The threshold of stimulation was determined by the minimal contraction of the muscle connected with the stimulated nerve. We measured the threshold value of the voltage at the output of the generator and also the voltage at a known resistance (from 18 kΩ to 1.2 MΩ in different series of experiments) with subsequent calculation of the amplitude value of the current. To measure the voltage we used the MVL-3-1958 tube millivoltmeter with a cathode follower or a cathode oscillograph such as the "Duoscope" (German Democratic Republic). The maximal sensitivity of the device permitted recording changes of the amplitude value of the current exceeding 0.05 μA.

In one of the experimental series we compared the thresholds of stimulation with an instantaneous and smooth switching on of the current. The first was accomplished by means of a key, the intensity of stimulation was increased stepwise from the subthreshold value, and the value of the steps was (with repeated measurement) 5% of the threshold value. Smooth switching on of the current was accomplished by slow (3-5 sec) turning of the handle of a potentiometer, this rate was constant for all types of stimulations. The duration of each stimulation necessarily exceeded the effective time for the types of current studied. Individual tests were repeated every 2-3 min. The results of the control determinations (investigation in an order of increasing or decreasing frequencies, alternation of investigations of various types of current, repetition of tests, etc.) indicated the reliability of data obtained; the variations of the indices studied under these conditions do not exceed 3-5% of their values.

Stimulation Threshold (in μA) of Half-Wave Rectified and Alternating Currents of Different Frequency (M ± m)

Type of current	Frequency (in cps) 20	50	100	200	500	1 000	3 000	5 000	10 000	20 000
Half-wave	1,6±0,2	1,4±0,1	1,4±0,2	1,8±0,2	4,0±0,6	6,7±1,2	17,8±2,5	34,5±3,6	90,6±15,0	280,0±66,4
Alternating	1,5±0,1	1,0±0,1	0,9±0,1	1,2±0,1	2,3±0,3	3,6±0,7	8,1±1,6	12,4±1,3	25,8±5,1	60,3±10,2
P	>0,5	<0,02	<0,05	<0,05	<0,05	<0,05	<0,02	<0,001	<0,01	<0,02

The threshold alternating current naturally caused excitation at the electrode, near which the excitability of the nerve was higher owing to the proximity of Ranvier's nodes or for other reasons. Therefore, in this work, the stimulating effect of the alternating current was compared with the stimulating action of the direction of the rectified current which produced a smaller threshold value and, apparently, caused excitation at the same point of the nerve as the alternating current. Upon arranging the stimulating electrodes far from the area of the transverse incision, the thresholds of stimulation to a rectified current of both directions differed little from one another in most experiments.

The results of the experiments were subjected to statistical analysis of the variance.

EXPERIMENTAL RESULTS

In the first series of experiments we compared the threshold values of the alternating and rectified currents with a smooth increase of their intensity. The results of the investigation showed that with an increase of frequency the threshold for the alternating current becomes lower than for the half- and full-wave rectified currents. The difference between thresholds in all experiments is minimal or absent at a frequency of 20 cps and maximal at the most frequent rhythm. Thus, at a frequency of 10,000-20,000 cps the threshold for the half-wave current exceeds by a factor of 3-5 the threshold for the alternating current, and in the case of the full-wave current the threshold at a frequency above 3000-5000 cps is frequently not determined at all. These characteristics were manifested in all methods of stimulation. The table shows the results of one of the series of experiments.

We see from the table that the threshold for the half-wave rectified current at a frequency of 20 cps virtually coincides with the threshold of the alternating current ($P > 0.5$). At higher frequencies, the threshold of the half-wave current exceeds that of the alternating, at the maximal frequency used (20,000 cps) the former exceeds the latter by a factor of 4.6.

The question arises concerning what underlies the appreciable difference of the thresholds of the alternating current and the thresholds of the half- and full-wave rectified currents. It is known that a rectified current can be represented as a constant component equal respectively to 0.32 and 0.46 of the amplitude value and sum of the sinusoidal harmonics [2]. We can assume that with a smooth switching on of the current the stimulating effect of the constant component is lost owing to accommodation to it.

This assumption was checked by a special series of experiments in which, after determining the thresholds of the half-wave current of varying frequency, the nerve was stimulated through the same electrodes by an alternating current (from the three G-2A) against a background of a direct current (from batteries) whose magnitude was equal to the constant component of the threshold of the half-wave current at a given frequency. Thus, the half-wave current from an alternating and direct current was "modeled." The results of the experiment showed that the thresholds of the alternating current against a background of the effect of a direct current are very close to the thresholds for the half-wave rectified current. For example, at a frequency of 5000 cps they are respectively 30.8±1.8 and 30.6±2 μA (the averages of ten experiments). Evidently, the constant component, without rendering a stimulating effect, causes electronic changes. The latter apparently explain the marked increases of the thresholds at frequent rhythms of the half- and especially full-wave currents in the experiments of the first series.

We previously demonstrated the pronounced changes of the thresholds to frequent rhythms of an alternating current under the effect of a constant current [3]. Furthermore, an appreciable increase of the thresholds at frequent rhythms of the rectified current depends on a greater absolute magnitude of the constant component in comparison with it at thresholds for infrequent rhythms. The greater increase of thresholds for the full-wave current can be explained both by the greater magnitude of the constant component and by the fact that the frequency of its fundamental harmonic is double the frequency of the first harmonic of the half-wave current. The latter is explained by the fact that the optimal frequency of the full-wave current is shifted to the side of infrequent rhythms in comparison with the half-wave and alternating currents.

In the last series of experiments we compared the threshold of the rectified current with a smooth and instantaneous change of its intensity. The thresholds of an alternating current with a frequency of 20-200 cps practically coincide in both methods of switching on the current. The thresholds for higher frequencies are somewhat higher with smooth switching on than with instantaneous.

A different picture was noted with respect to the rectified current. First, its thresholds at all frequencies are noticeably higher in the case of smooth switching on. Second, the thresholds at higher frequencies increase much more abruptly with smooth switching on and exceed by tens of times the thresholds with instantaneous switching.

It is characteristic that the thresholds for the rectified current with its instantaneous switching on are identical for frequencies above 3000 cps. Since the frequency of the current in this case is not reflected on its thresholds, they apparently depend only on the constant component. Actually, the results of a parallel determination of thresholds for the rectified and direct current confirmed this assumption.

Thus, the stimulating effect of half- and full-wave rectified currents depends (at least under certain conditions) on their components. This circumstance can be one of the causes for the predominance of the stimulating effect of a rectified current in comparison with that of the alternating or, conversely, can depend on the conditions of the investigations [1, 4-7]. It was shown in the work that among these conditions the method of switching on the current and its frequency play an important role.

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