ELECTRO-THERAPY OF PARALYSES
(BASIC PRINCIPLES AND METHODS OF APPLICATION)

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IN recent years a great advance has been made in the field of electro-therapy, in the treatment of paralyses. This is due to the fact that modern electrical technology is now able to provide the means of satisfying the demand for special apparatus which has long been made by physiologists.

There is, however, still no widespread knowledge of either the physiological principles of electric current application or the technique of treatment which, especially in the case of paralysis, is of such vital importance even though there are but few therapeutic agents which can look back on so long a history and which have been examined in such detail, both clinically and in the research field, in respect of their possible applications. This is particularly true of the modern methods of electro-diagnosis and electro-therapy which until quite recently were unknown. Accordingly, it is the aim of this paper, to present the basic physiological principles of modern excitation current therapy and diagnosis, as well as the methods of application, particularly in the treatment of paralyses.

Up till now, electric currents used in medicine have generally been divided into two classes: galvanic (or direct currents) and faradic (alternating currents) (Fig. 1). Experience, however, has made it increasingly clear that this division, adopted from electrical technology, no longer holds in the light of present physiological knowledge and the increased demands of diagnostic and therapeutic work. It is now possible to produce almost any form of current by means of electronically operated instruments; current forms which in their manifold variety cannot be covered by the term galvanic or faradic; so that in principle it has become obvious that there is no distinction, either diagnostically or therapeutically, between a faradic current and a correspondingly interrupted direct current (Fig. 1). It is advisable, therefore, as KOWARSCHIK has suggested, to find a common denominator for both forms of curernt and to combine them under the term "excitation current." This has the effect of dividing electrotherapy (or low frequency therapy) into (a) galvanization, i.e. application of constant direct current, and (b) application of excitation currents. In spite of their manifold variety, the various excitation currents can be easily and accurately defined by determining the components or excitation parameters, such as duration of impulses and intervals, steepness of the impulse gradient and the impulse intensity (Fig. 2). Modern electronic instruments can readily generate almost any excitation current defined by such components, thus ensuring that the current can be constantly reproduced and that comparative examinations can be made.

As a result of extensive experiments on animals, the first of which date from the middle of the last century, and of the research work carried out in recent years, especially in America, there is no doubt as to the value of electro-therapeutical treatment of paralysis. Recent work has been aimed less at obtaining proof of its value, as discovering the most favourable form of current from the therapeutical point of view.

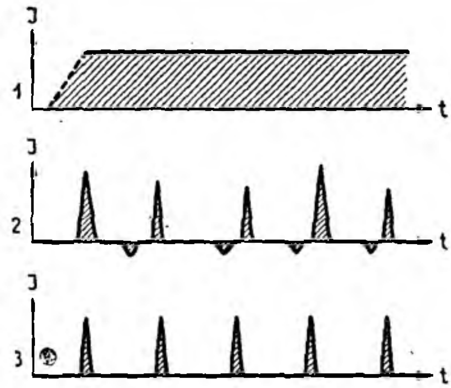

Fig. 1.
(Fig. 1.) 1.—Galvanic current, constant D.C. 2.—Faradic current, original form, produced by an induction coil, entirely irregular, not measurable. 3.—Triangular impulse sequence, corresponding to faradic current, exactly defined and measurable.

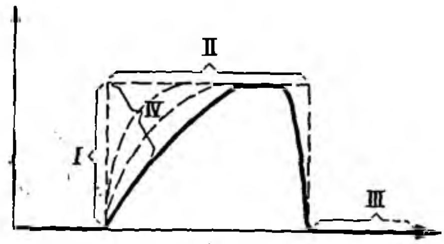

Fig. 2.
(Fig. 2). I.—Intensity of Impulse or peak intensity of current II.—Impulse duration. III.—Period of rest. IV.—Increase or gradient of impulse.

The oldest method of applying electric current is by simple galvanization, meaning the application for therapeutical purposes of a constant direct current[1]).

Galvanization produces in the body quite definite, characteristic reactions, which can be used to advantage for the most varied therapeutic purposes. Since most excitation currents can be derived from an interrupted, chopped, amplified or otherwise modified direct current, they also have certain basic qualities in common with it. Hence a knowledge of the effects of direct current also forms the common basis for an understanding of the effects of excitation currents. These will be briefly examined, because of the practical importance of simple galvanization.

The human body can be represented as a semi-conductor of electric current, the current flows through it being effected by means of ions. This is not so in the case of metals, where current flow is effected by electron displacement. Thus a change in chemical structure of a human body occurs when a current is passed through it.

1) The foundations of all later clinical experience was laid in the last century by the great electrotherapeutists, chiefly by REMAK, the real founder of galvano-therapy.

The ions responsible for conducting the current are formed by the break-up (dissociation) of the electrolytes into positively and negatively charged particles. The moment a circuit is established, the positively charged electrolytic components (or cations) start moving towards the cathode, and those nagatively charged (anions) towards the anode. In addition to the migration of the dissociated water and salt molecules, a movement of actual liquid particles which occurs, takes place from the anode towards the cathode, i.e. in the so-called direction of the current. This process is known as cataphoresis, or in general as electrophoresis. It involves the participation of the un-disintegrated (i.e. non-dissociated) water and salt molecules, as well as the molecules of colloids, lipoid substances, albumen, sugar, etc. suspended in the blood or tissue fluid. There is no doubt that the combined effect of ionic migration of the dissociated elements, together with electrophoresis, play a leading part in the curative effect of galvanic currents, although the actual degree of cure achieved by either process is difficult to assess.

The principal effect of ionic migration is to produce a change in the chemical concentration of both the tissue fluid and cell substance. The cause of this change in concentration may be found mainly due to the varying conditions of permeability, met with at the cellular dividing walls, and wherever two media of different kinds meet. Activation and mobilisation of innumerable halogen and mineral ions results, which in turn brings about a strong stimulation of all metabolic and biological processes. The vasomotor and trophic effects of galvanic current are rendered visible, especially underneath the electrodes, as a bright reddening of the skin which is hot to the touch. By means of thermo-electric measurements, KOWARSCHIK among others, was able to show that the temperature of the skin could, by means of galvanization, be increased by more than 2—3° C. The ensuing hyperaemia is stronger than after massage or even short wave treatment. This hyperaemia, however, extends not only to the skin but also to the more deep-seated tissue section, and moreover, it persists for a very long time. This increased tendency to vasodilation can often be detected for days afterwards. The persistent hyperaemia reacts favourably on the course of the disease in many ways, especially in the improved trophicity of the tissues, which is nearly always strongly affected by paralyses, particularly poliomyelitis, and certain circulatory affections of other origins.

A further curative effect of galvanic current, (the sedative and analgesic component) is widely used in the treatment of neuralgic and neuritic ailments. Frequent use is made, even now of the soothing effect of "descending galvanisation"[1]) in treating spastic paralytics, hemiplegia patients, etc., as introduced into electro-therapy by SCHEMINZKY.

The importance of galvanic current in the treatment of paralysis, albeit only as an aid and a preparation for subsequent electro-gymnastics, is still not always fully recognised. Since a continuous direct current, at the intensities used in therapeutic treatment, produces no contraction of the muscles, it is sometimes assumed that it has no affect on paralytic disorders either. That this assumption is wrong has been shown by numerous experiments on animals, some of them conducted in the middle of last century (by REID, DÉJERINE, GÖTZE, PIONTKOWSKI, LENOCH and others). Mention has already been made of the great importance of an increased and improved circulation in regenerating paralysed muscles. This does not, however, exhaust the effects of galvanic current. In fact, even after a galvanization of short duration (especially under the cathode) the excitation threshold is materially reduced. This reduction can be expressed as an easier susceptibility of the nerv-muscle systems concerned, not only to electrical stimuli (reduction of the chronaxy, etc.) but also to purely mechanical stimuli (testing of the tendon reflexes). Thus a muscular system pre-treated with constant galvanization not only shows an increased and stronger reaction in subsequent impulse or surge current therapy, but the responsiveness to self-created stimuli (i.e. emanating from the patient himself), is also increased. Hence, continuous galvanization (in the same way as a hot bath or electro-thermal bath, etc.) is just as suitable as a preparatory treatment for active movement exercises by the patient, as a subsequent course of exercises under electro-stimulation.

Constant direct current has, however, only rarely been used in the electrical treatment of paralysis. The practice has rather been to make use of the abrupt rise and fall of a direct current interrupted by means of a hand key, resulting in the well-known closing and opening contractions.

In addition to these galvanic current impulses of varying length, faradic current was also used. How physiological science regards faradic current supplied by an induction coil, formerly the only method used, is shown by the comments made by REIN[2]), which in view of their importance, are quoted verbatim, as follows:

> "Now that the effect of the form and the frequency of faradic current is well known, and its action on every individual nerve element has been established, it is time that this knowledge should be taken into account in medical practice. The most frequent source of current used, incidentally a very bad one, is the induction coil which gives a current whose form and frequency cannot be defined. Because of this, motor, sensory, and autonomic fibres in the nerve trunk are stimulated indiscriminately. Thus the whole muscle is made to contract, yet at the same time the blood vessels are also contracted and the pain receptors stimulated. This is certainly not the most appropriate method of medical treatment. Such a procedure is called 'faradization' as opposed to 'galvanization'. In view of the present stage reached in physiology and electrical technology, we should discard these archaic terms and antiquated instruments, and replace them by more up-to-date ones."

There is no doubt, that the faradic, galvano-faradic or Leduc currents still extensively used in clinics and medical practice to-day, do not meet the requirements of excitation currents, especially for intelligent and selective treatment of paralyses. The reasons why the application of faradic and key-controlled electrical currents can no longer be regarded as up-to-date for this purpose, and the requirements for the intelligent application of excitation currents will be dealt with below.

The usual faradic current produced by an induction coil is unsuitable, especially for treatment of paralyses, not only because it does not meet physological demands but also because it has other technical drawbacks which are manifested as irregular impulse duration, uneven pauses and variable current intensities. Moreover, the strength of the current can not be measured accurately; hence, in order to make a diagnosis, comparative tests have to be carried out on the corresponding healthy nerves and muscles. If pathological conditions exist on both sides, as is frequently the case, such a procedure is obviously impossible.

[1]) The expression "descending current," originally coined by PFLÜGER to denote the permeation by the current of a nerve in the direction of the muscle, is commonly understood, in a somewhat modified form, to mean that the anode is applied proximally, i.e. at the head, and the cathode distally, i.e. in the area of the lumbar portion of the spine. The assumption in this case is that the current flows (only) from the plus to the minus pole.

[2]) REIN, „Einführung in die Physiologie des Menschen" (Introduction to Human Physiology), Springer 1948, p. 314.

To illustrate the following paragraphs more fully, certain physiological aspects must be discussed in some detail, necessitating a certain amount of generalization and simplification. In doing so, the physiological data will be discussed from the standpoint of the diagnostic and therapeutic conclusions which follow:

1. Current Strength Pulse Amplitude and Rheobase

It is self-evident that, in order to stimulate a nerve or muscle, a certain minimum current strength, the so-called threshold value, is required. LAPICQUE has called the current strength needed to produce a minimum twitch, the basic threshold or the "rheobase." The determination of the minimum current strength which causes no stimulus reaction in a given period, is still the simplest method used to-day for purposes of diagnosis.

2. Duration of Current Flow and Effective Time

The mere determination of the current strength ("Rheobase") necessary to produce a minimum twitch has proved inadequate in fixing the susceptibility of a nerve, as no account is taken of the time factor. To produce a muscular contraction requires not only a minimum current strength, but also a fixed minimum duration of current flow, related to the current intensity. Moreover, the practical determination of the rheobase may give rise to considerable deviations and inaccuracies, largely because the (local) current density, which plays an important role, is not taken into account.

Similarly, the determination alone of the minimum time of current flow, (referred to as "effective time" by LAPICQUE and GILDERMEISTER), was bound from the outset to remain equally inadequate, as this again involves only one factor which is largely dependent on other values, i.e. current strength, and current impulse gradient. It is to LAPICQUE's merit that he introduced, from such considerations, the concept of chronaxy. Its determination involves not the current strength needed to produce a minimum twitch, but the period for which a current of a definite intensity, i.e. twice the rheobase intensity, must flow.

3. Excitation Time/Stimulus Intensity Curves and Rectangular Impulse Characteristics

Rheobase and effective time do not represent absolute values, but between the duration of an impulse and its intensity a definite relationship exists, which was formulated in the HOORWEG-WEISS Law. If, for instance, the duration of a (rectangular) impulse is reduced—within certain limits—the current strength must be correspondingly increased in order to produce a minimum twitch. On the other hand, long current flow periods require lower intensities. To illustrate this principle more fully, we shall represent the relationship between impulse intensity and flow duration graphically, i.e. by using a system of co-ordinates and plotting intensity on the ordinate and the duration of the current flow on the abscissa. This produces curves such as shown in Figs. 3a and 3b, which approximate to hyperbolae. Rheobase and chronaxy represent therefore only two points on a curve. It is obvious that a study of the entire curve presents a more complete picture of the conditions of susceptibility with which we are primarily concerned, than is obtained by merely selecting two points from it. Such curves, showing the relationship between intensity (or voltage) and duration of flow, required to produce a definite comparative reaction, are known as excitation time/stimulus intensity curves (or excitation time/stimulus voltage curves) or, for short, "I/t curves."

In order to illustrate the important section of the curve (the ascending part), more clearly than would be possible with a linear scale, a logarithmic scale is normally adopted for either ordinate or abscissa, (i.e. intensity or time), or both.

The shape of the curves show that the product of intensity and time, i.e., the quantity of electricity, is an important factor in producing a reaction. This product, however, is by no means constant ($I \times t =$ constant) as might be concluded from the considerations mentioned at the outset. The lack of constancy can be traced to the counter-effects set up in the body, arising partly from the diffusion of ions, which increases with the duration of the concentration gradient brought about by the current; and partly from the change caused by the current, to the selective permeability of the membranes, which is the main cause of the change in concentration. In view of these counter-effects it can be seen that lengthening the duration of any given weak current will soon cease to produce further contraction stimuli. Similarly, even if very powerful currents are used, a certain minimum time of current flow must be guaranteed.

4. Speed at which Current Rises and Accommodation

The contraction producing effect of a current depends, however, not only on its intensity and duration, but also on the speed with which it reaches its maximum intensity (i.e. peak value). DU BOIS-REYMOND already realized that the threshold value required to produce a minimum twitch in a sound voluntary muscle is smallest when the current rises to a peak value almost immediately, i.e. in a minimum of time. In sound muscles, therefore, the current is more effective, the more steeply it rises. If, however, the current rise is delayed, i.e. when current "creeps" in, the peak current required to produce a stimulus of equal intensity must be considerably increased (see Fig. 3a). This phenomenon can be explained by the counter-effects set up in the body, immediately an electrical stimulus is applied. The body is, as it were, "surprised" by a more or less sudden application of the stimulus and successful stimulation can only be produced by this means. On the other hand, the tissue soon adapts itself to a stimulus impulse of moderate rise, in which case a materially stronger current is required to produce the same effect.

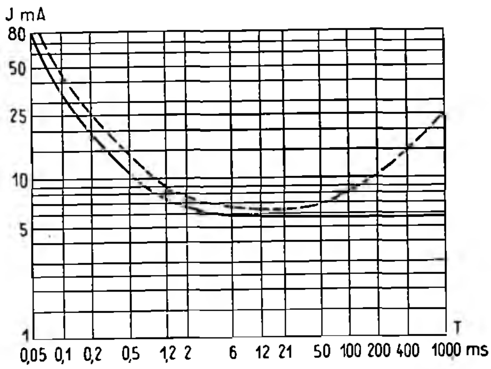

Fig. 3a.

Fig. 3a. Excitation time/stimulus intensity curves of a normal nerve muscle system. ———— I/t curve with rectangular impulses, rectangular impulse characteristic (RPC). — — — — I/t curve with triangular impulses, triangular impulse characteristic (TPC). On the basis of an impulse duration of 1000 ms, amperages of 5.8 mA in the case of rectangular impulses and 25 mA in the case of triangular impulses give an accommodability quotient A of $A = \frac{25}{5,8} = 4,3$.

The quotient for normal accommodability is *approximately* = 3—6.

DU BOIS-REYMOND and NERNST have coined the expression "accommodation," to describe this process of adaptation to the stimulus, and the capacity to accommodate is known as "accommodability". It is inherent to a high degree only in healthy cerebro-spinal nerves and sound voluntary muscle. In a denervated muscle, the power of accommodation is lost to a large extent, thus "creeping", a phenomenon associated with healthy muscle, is impossible. This means that a paralysed muscle can be made to contract even with a relatively low current rise, while adjoining muscle remains unaffected owing to its capacity of accommodation (see Fig. 3b).

This difference in the reaction of healthy and denervated muscle to stimuli, provides the key to the problem of selective stimulation of paralysed muscle. As long ago as 1904 REISS drew attention to this decisive difference which is equally significant for both, diagnosis and therapy. Later, WYSS, TURRELL, DUENSING, KOWARSCHIK and others have investigated the practical exploitation of accommodability, or its loss, for diagnostic and therapeutical purposes.

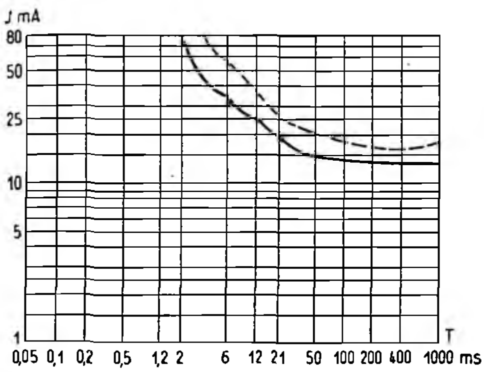

Fig. 3b. Excitation time/stimulus intensity curves of a denervated nerve muscle system. ———— I/t curve with rectangular impulses, rectangular impulse characteristic (RPC) — — — — I/t curve with triangular impulses, triangular impulse characteristic (TPC). Both curves are shifted distinctly upwards and to the right. The accommodability has been almost entirely lost: $A = \frac{18}{14} = 1.2$.

According to SCHRIEVER, a good measure of accommodability is the so-called stimulation quotient. This is found by dividing the threshold value for long triangular impulses (expressed in mA), by the threshold value for rectangular impulses. In the case of a current reaching its peak value gradually, the current strength required for a minimum response (the threshold for a long triangular impulse) is also called the galvano-tetanus threshold value. The current strength required to produce a minimum twitch; the impulse beginning and ending abruptly, and having a duration of at least 1000 ms; has long been known as the "rheobase" (the threshold for a long rectangular impulse).

The stimulation quotient, (or the galvano-tetanus quotient), is obtained from the ratio.

$$\frac{\text{galvano-tetanus threshold value in mA}}{\text{rheobase in mA.}}$$

The greater the quotient, i.e. the higher the galvano-tetanus threshold in relation to the rheobase, the better the accommodability, but as the two values approach each other, i.e. the ratio tends to unity, accommodability decreases accordingly. A simple method of assessing accommodability is to determine the rectangular and triangular threshold for impulses of 1000 ms duration. The quotient thus results from the ratio

$$\frac{\text{Triangular impulse threshold in mA}}{\text{Rectangular impulse threshold in mA}} = \text{accommodability(A)}$$

Normal values lie between 3 and 6, pathological values below 3; with a quotient of 1, accommodability ceases entirely.

5. Periods of Rest and Refractory or Recovery Period

In nerve or muscle stimulation (using a single current impulse) the effect of the current depends largely on three factors, i.e. current intensity, time of current flow and impulse gradient. However, as soon as we apply impulses in rapid succession, definition of this impulse sequence requires a further factor which is physiologically no less important, viz. the period of rest between the individual impulses. The importance of this factor, both, in diagnosis and for therapy, was recognized only comparatively recently.

The time required by an individual cell of excitable tissue to rebuild the reduced energy potential after excitation has ceased, is described as the refractory period. During this period the cell cannot be successfully stimulated. Thus single muscle fibre cannot be made to perform full and continuous contractions, but will always respond even to continuous stimulation, with small rhythmic contractions only. All the individual fibres in a complete muscle work on the same principle, except that a phase displacement occurs in such a manner, as to cause a large number of fibres to be in a state of refractory rest while others undergo contraction.

Thus if a muscle is made to contract by a too rapid succession of stimuli, regardless of the refractory period, the contraction intensity rapidly falls, the stimulus intensity remaining constant, since an increasing number of muscles fibres, which can no longer rise to their previous level of energy, are eliminated from the next stimulus.

In selecting the rest period these facts must therefore be taken into account, and the selection made according to the extended refractory or recovery period.

(To be concluded in next issue.)