Studies on the Motile Function of the Fallopian Tube

Report 2. Effect of Audio-Rectangular Pulse Wave Current on the Motile Function of the Fallopian Tube

By

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INTRODUCTION

The oviferous function of the Fallopian tube is an important matter from the view-point of reproductive physiology correlated with the question of genesis of sterility and ectopic pregnancy. As possible factors lying at the base of the process, we may enumerate chemotaxis, ciliary movement and muscular movement, and it is accepted that the last item plays the leading role here. Therefore, the function of the tube should be adequately interpreted by elucidating its muscular movement. In the previous Report 1, the present author reported on the results of studies on the correlation of estrual periods and sex hormones with the features of the tubal movements, i.e. the muscular contraction, the form, the pace-maker activity, the fatigability and the conductivity. In succession, I conducted a study on the effect of audio-rectangular pulse-wave current (ARC) and at the same time made fundamental researches on the possibility of introducing ARC therapy into the clinical practice for treating salpingopathic cases. I had the pleasure of ascertaining that ARC therapy may be successfully adopted in treating diseases in the Fallopian tube for which only intubation, medication and surgical operation have been applied, generally with indifferent results, as reported in the following.

MATERIALS AND METHODS

Vital and excised Fallopian tubes of rabbits were used as the experimental materials.

For the experiment, the apparatus shown in Fig. 1 were designed. A is the devise for recording the contraction of the longitudinal muscles (strictly speaking, some circular muscles also come into the play); the Fallopian tube specimen mounted in the Sugi-type isolating vessel of plastics is partitioned into

Fig. 1. Experimental apparatus.

e : Stimulating electrode, s_1 & s_2 : Separating wall, t : Fallopian tube

three sections electrically insulated from one another by the two insulating walls S_1 and S_2 . The ends of the specimen were pinned down on the bottom of the vessel covered with a cork plate, and the insulation points were kept unmovable by traction of a lever. The distance between S_1 and S_2 was 1 cm and the length of the specimen between them was fixed at ca. 1.5 cm. A hook was mounted at the median point of this 1.5 cm length and the movement of the specimen at this point was transmitted to a mechanogram. B was the device for recording the contraction of the circular muscles (strictly speaking, some longitudinal muscles also come in to make up the movement); the tubal specimen was pinned to a cork pillar set up at the middle of the insulating box, for recording the movement in the transverse direction. C is the device for recording the insufflation curve of the tube; a polyethylene tube was inserted from the ampullar end and O_2 gas was sent in through it at the velocity of 30 cc/min; the other end of the tube specimen was left free always for the length of 1 cm. The intratubal pressure was recorded with a Takebe's Grafix insufflation recorder. D is the apparatus mainly consisting of 2 large electrodes between which the tube specimen can be stimulated uniformly in all its parts. E and F show the process of treating vital specimens in schema. The insulating chambers were filled with Tyrode's solution kept at 22–26°C for inhibiting automatic movements and aerated with O_2 or 95% O_2 + 5% CO_2 . The electrodes used for stimulation were Ag or Zn-ZnSO₄-agar-Ringer electrodes, which were employed in various arrangements and

combinations. The mechanograph was used to record the isotonic and the isometric contraction with an optic lever or a mechano-electric transducer RCA 5734. ARC from an electronic stimulator and 50 cycle AC were used for stimulation.

RESULTS

1. Effect on longitudinal and circular muscles: Fig. 2 shows the correlation of the insufflation pressure to the frequency of the stimulating ARC, when the voltage was kept constant at the optimal voltage, the duration of a stimulating pulse wave was kept at 1 msec. and the stimulating duration was kept at 5 sec. while the frequency is changed in the range of 1–1000 c/sec. When the frequency fell below 5 c/sec. or rose above 500 c/sec., the insufflation pressure showed little change; at about 7 c/sec. a response begins to appear in the insufflation curve, rising to the maximum at 30, 50 or 100 c/sec. (in the case illustrated, at 30 c/sec.), then declining rapidly to nothing above 1/100 of that at the maximum level. A similar relation was apparent in the contraction curve of circular muscles, but the contraction curve of the longitudinal muscles was somewhat different, the frequency of maximum effect being scattered more widely, often up to 900 c/sec., though in most cases the range between 50 and 300 c/sec. was the normal. In the correlation between the threshold voltage and frequency of the stimulating current too, the longitudinal and the circular muscles showed some dissimilarity, the latter being found to respond effectively to ARC of a lower range of frequency than the former. Thus, it was revealed that the longitudinal and the circular muscles of the Fallopian tube have respectively different electrophysiological characteristics, and that the insufflation of the tube is almost entirely due to the contraction of circular muscles. The other three factors, voltage, duration of the

Fig. 2. Effect of ARC frequency on the circular muscular contractility. Signals show frequency in c/sec.

Fig. 3. Effect of ARC voltage on the longitudinal muscular contractility. Abscissa: Voltage in V. and ordinate: Contractility in percentage (max. contraction is decided on 100%).

pulses and the duration of the applied stimulation in the experiment showed no specific difference in the response of longitudinal and circular muscles. When the amplitude of a certain stimulated contraction, by percentagment compared with the maximum contractibility of the tube which was decided to be 100%, is applied as the measure of the effectiveness of stimulation, the results under varying voltage and duration of a pulse of applied stimulation were as follows. The

Fig. 4. Effect of 50 cycle AC voltage on the longitudinal muscular contractility.

effect of changing the voltage was unequal under different frequency, as shown in Fig. 3, for while at the duration of pulses of 1 msec. and the duration of the stimulation of 5 sec., the response reached the maximum at 5V or so in the range of frequency of 100–200 c/sec., when the frequency is too low (5–10 c/sec.) or too high (500–900 c/sec.) usually no raise of the voltage can effect maximum contraction. As in Fig. 3, however, many individual results of measurements under stimulation of the longitudinal muscles are illustrated, some exceptional individual differences are observable, e.g. in one case, the maximum response is seen in the range of frequency of 600–900 c/sec.. In the electric field of a 50 cycle AC, the current density of around 2 V/cm seemed to be most effective in stimulating longitudinal muscles, considering the change in the wave form of contraction (Fig. 4); a lower voltage was insufficient in causing maximum contraction, while a higher voltage would cause delay in the recovery of the contracted muscle.

Fig. 5. Effect of ARC pulse duration on the longitudinal muscular contractility. Abscissa: Pulse duration in msec.

Under constant voltage of 5V and stimulating period of 5 sec., as exemplified in Fig. 5, a longer duration of the electric pulse caused stronger contraction of the longitudinal muscles, the maximum contraction being realized when the pulse duration was slightly beneath that compatible with the frequency of the applied ARC. When the frequency was outside the effective range, no prolongation of the pulse duration could bring about maximum contraction, while within the range of 0.05–0.01 msec. of duration no variation of the frequency could effect realizing the maximum in muscle contraction either.

When the voltage was kept fixed at 8 V and the pulse duration at 1 msec., the contraction of the circular muscles under varying duration of the applied stimulation was as shown in Fig. 6. When the stimulation was prolonged, the contraction is seen to amplify, but the mode of contraction shows that an over-

Fig. 6. Effect of ARC polarization on the circular muscular contractility. Abscissa: Polarization in sec.

Fig. 7. 50 cycle AC polarization on the longitudinal muscular contractility. The numerals show polarization duration in sec.

prolongation of the stimulation results in forced abnormal contraction. As shown in Fig. 7, under stimulation with 50 cycle AC, the longitudinal muscles lose the capacity of recovery after overprolonged stimulation. The optimum duration of stimulation was found to range between 3 and 5 sec., as revealed by contemplation of the curves.

2. Effect on the type of movement: Movements of the Fallopian tube of the segmented type, conductive as well as non-conductive, and peristaltic type

Fig. 8. ARC frequency on the mode of the Fallopian tube.

Fig. 9. Spasmolytic action of ARC on motile function of the Fallopian tube. Upper shows spastic tubal contraction, middle ARC polarized and lower success in spasmolysis.

could be induced by ARC stimulation. The curves and the conductivity of the movements induced depended on the moving site and the stimulated point of the tube and the mode of applying the tonus, as well as the estrual periods and the individual differences, but as shown in Fig. 8, we might summarize that the form of the movement is generally correlated with the frequency of the stimulating ARC in a definite way; for peristaltic movements and conductive segmented

movements showed selective response to ARC of 30–300 c/sec. and 100–900 c/sec. frequencies respectively. At 5–20 c/sec., only non-conductive segmented movements and twitches could be induced, but movements of these types did always come forth, whatever the frequency of the current is.

3. Effect on the motor function: When a contracted tubal muscle in a state of convulsion is polarized with ARC of 30–50 c/sec. frequency, the tonus is slowly slackened, the amplitude is gradually widened and the rhythm recovers regularity from the original irregularity (Fig. 9). Under stimulation with 50 cycle AC too the result was similar, but only less prominent. ARC polarization also showed reactivating effect; an excised specimen fatigued in a salt solution could be made to recover from fatigue with ARC of 30–500 c/sec. frequencies. Such a reactivating effect can be inferred from the fact that the resuscitation is expedited by ARC polarization in the case of revitalizing excised specimens in nutritive solution. Anodal polarization seemed preferable in effecting such activation, probably because application of anodic potential enhances the permeability of a membrane and thus contributes to the improvement of the conductivity and enlarges the amplitude. Such spasmodic and activating effects were manifest in the cases of both the longitudinal and the circular salpingian muscles.

DISCUSSION

The leading opinions on the oviferous mechanism support either the ciliary motion theory or the muscular movement theory. Grosser¹⁾ and Kneer²⁾ observed that foreign bodies in the Fallopian tube is carried on by movement of cilia, but Sobotta³⁾ pointed out that in guinea-pigs, mice and rats the distal portion of the tube is devoid of cilia and Tröscher⁴⁾ and Tietze⁵⁾ observed that cilia decrease in number in the period of ovulation, so that the ciliary motion theory is tainted with some hardly reconcilable defects.

On the other hand, the muscular movement theory has obtained support by many authors; Kok⁶⁾, Gogoberidse⁷⁾, Mikulicz-Radecki⁸⁾ and Doyle⁹⁾ conducted experiments on the mode of movement and oviferous process in human and some animal salpinx. Cella¹⁰⁾, Manzi¹¹⁾, Geist^{12–13)}, Wimpfheimer¹⁴⁾, Bernstein¹⁵⁾ and Binder¹⁶⁾ studied the correlation between the muscular movement and sex hormones, and Wimpfheimer,¹⁷⁾ Rubin^{18–19)}, Marbach²⁰⁾ and Davids²¹⁾ perfected methods of gastubation in their attempt to grasp the salpingian muscular movements from the clinical stand-point. The present author has previously reported in Report 1 on the study on such movements as analysed from the angle of muscular contraction, form of movement, pace-maker activity, fatigability and transporting ability and in correlation with the different estrual periods and sex hormones. Csapo²²⁾ has made electrophysiological experiments on uterine muscles, but no data of such studies on the Fallopian tube has ever been published. I

have elucidated by experiments that the longitudinal tubal muscles show electrophysiological characteristics different from those of the circular tubal muscles — an interesting discovery, I believe. The findings that ARC has the effects of spasmolysis and activation on salpingian muscles indicate that ARC therapy for salpingopathies is at least in principle as possible as for diseases of skeletal muscles and nerves. The effective action of such a therapy will be based on Suzuki's third effect²³⁾ of the polarizing electrodes in raising the excitability at the anode and lowering it at the cathode. I am now devising an apparatus for applying ARC to the vital human Fallopian tube and will report the clinical results obtained with it in the future.

SUMMARY

The effects of audio-rectangular pulse wave current (ARC) and 50 cycle alternating current on the Fallopian tube of rabbits were studied and the following results were obtained:

1. The longitudinal and the circular salpingian muscles showed different responses to ARC, the optimum frequency being 50–900 c/sec. for the former and 30–100 c/sec. for the latter.
2. The correlation of the frequency, the voltage and the duration of pulses and the duration of applied stimulation with ARC to the intensity of muscular contraction was studied also.
3. ARC showed selective effect on different types of the muscular movements.
4. ARC was found to have spasmolytic and activating effects when applied to the salpingian muscles.

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