PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL BIOLOGY AND MEDICINE 151, 484-486 (1976)

Microvibration: Capable of Inducing Spontaneous Contractions in Smooth Muscles (39240)

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(Introduced by T. Yamada)

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A distinctive feature of visceral smooth muscle is its ability to respond to stretch by developing active tension. The occurrence of spontaneous contractions is often observed when a sustained stretch is applied to the quiescent muscle. In some cases, the elicited contractions last for a long time. In the others, however, one or a few contractions only occur immediately after stretching. This may suggest that, in addition to the magnitude of elongation, the rate of deformation also plays a significant role in eliciting the spontaneous contractions. The present study was undertaken to investigate the response of the visceral smooth muscle to the imposed vibration of small amplitude.

Materials and methods. Longitudinal strips, 15 mm in length, were prepared from the isolated ureter and portal vein of dogs. Each strip was placed in an organ bath filled with physiological saline kept at 37°. The upper end of a strip was connected with a force transducer (Sinko-Tsushin UL-20). The limiting frequency of the transducer system, at which the decrease by 3 dB occurs, was 55 Hz. The lower end was connected with the movable shaft of an electromagnetic vibrator of domestic make. Frequencies and amplitudes of the vertical sinusoidal motion of the shaft used in the present study ranged from 1 to 90 Hz and from 50 to 150 μm, respectively. The connected strip was stretched and released cyclically as the shaft moved up and down in a vertical line. Hereafter, this cyclic stretch-and-release will be referred to as microvibration.

Before application of microvibration, the ureteral strip was elongated by about 30% and the portal one by about 50%, so as to return their lengths to the respective *in vivo* lengths. The resting tension, i.e., the tension at the *in vivo* length, of the ureteral strip was between 200 and 500 dynes and that of the portal strip was about 300 dynes. The cyclic strain, i.e., the relative extension of strip resulting from application of microvibration, was less than 1% at its maximum, since the cyclic strain is defined as the ratio of microvibratory amplitude ($\leq$150 μm) to the length of strip before application of microvibration (= 1.3 × 15 mm or 1.5 × 15 mm).

The resting and developed tensions were recorded by means of an electronic polyrecorder (Toa Denpa EPR-2TB), the limiting frequency of which was 2 Hz.

Results and discussion. Figure 1 demonstrates the effect of microvibration on the ureteral strip. In 12 of 21 cases, the microvibration could elicit spontaneous contractions in the quiescent strip (Fig. 1A). The magnitude of each successive contraction increased gradually until a maximum steady level was reached. The contractions went on occurring as long as the strip was vibrated, occasionally for more than 1 hr. Latent times varied with each individual response over a wide range, from 5 sec to a few minutes. However, most of them were distributed between 15 and 80 sec. Frequencies of the induced spontaneous contractions ranged from 0.5 to 6/min. A few after-contractions, usually larger in magnitude, were observed immediately after interruption of the microvibration. The smallest amplitude of microvibration required to produce the response was about 50 μm, so that the threshold cyclic strain was estimated to be less than 0.3%. Up to the amplitude of 150 μm, the greater the amplitude, the faster the induced rhythm and the larger the magnitude of each contraction, provided that the frequency of microvibration exceeded 5 Hz. Any microvibrations at frequencies of less than 5 Hz were not effective, even with the greatest amplitude, in producing the response. Stepwise increase

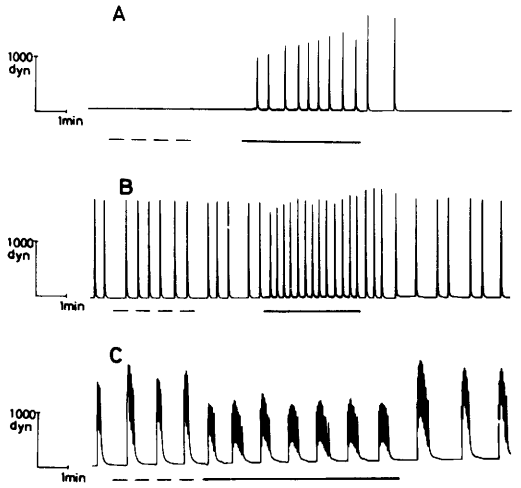

FIG. 1. Effect of microvibration (MV) on mechanical activity in the isolated ureter. A: Elicitation of spontaneous contractions in the quiescent strip (MV: 30 Hz, 100 μm). Two after-contractions, larger in magnitude, occurred in succession after interruption of MV. B: Acceleration of the existing rhythmicity (MV: 20 Hz, 100 μm). C: Increase in the number of twitches involved in an incomplete tetanic wave (MV: 30 Hz, 80 μm). The increase was so remarkable that a reduction was produced in the magnitude of individual twitches. After-effect was clearly demonstrated in the first wave after stimulation. Broken lines indicate zero tension level and dark lines the duration of MV.

of the frequencies from 5 to 30 Hz brought about a reduction in latent time and an acceleration of contraction rhythm. At frequencies of between 30 and 90 Hz, no appreciable frequency-dependent differences were observable among the responses induced.

Microvibration affected the existing spontaneous contractions as well (Fig. 1B). In 69 of 74 cases, an acceleration of the existing rhythm was brought about by the stimulation. A reduction in magnitude of individual contractions was occasionally observed when the microvibration produced a striking acceleration. A few after-contractions, as compared with the existing, were greater in magnitude and shorter in period. Alterations of the effect with changes in parameters of the stimulation were almost the same as those observed with the quiescent strip. At times, several twitches which occurred successively in a volley were formed into an incomplete tetanic wave (Fig. 1C). Microvibration increased the number of twitches involved in each wave.

Essentially the same results were obtained with the portal venous strip. Applied microvibrations elicited spontaneous contractions in 8 of 11 quiescent strips (Fig. 2A) and accelerated the existing rhythm in 15 of 20 cases (Fig. 2B). Successive portal

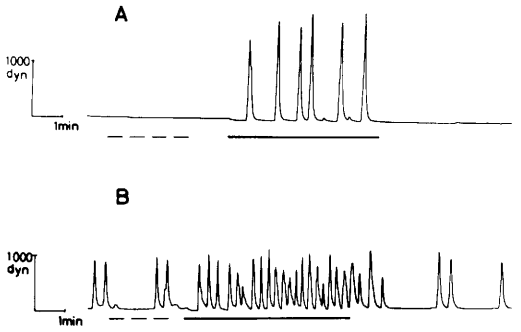

FIG. 2. Effect of MV on mechanical activity in the isolated portal vein. A: Elicitation of spontaneous contractions in the quiescent strip (MV: 40 Hz, 150 μm). B: Acceleration of the existing rhythmicity (MV: 30 Hz, 150 μm). Broken and dark lines indicate the same items as in Fig. 1.

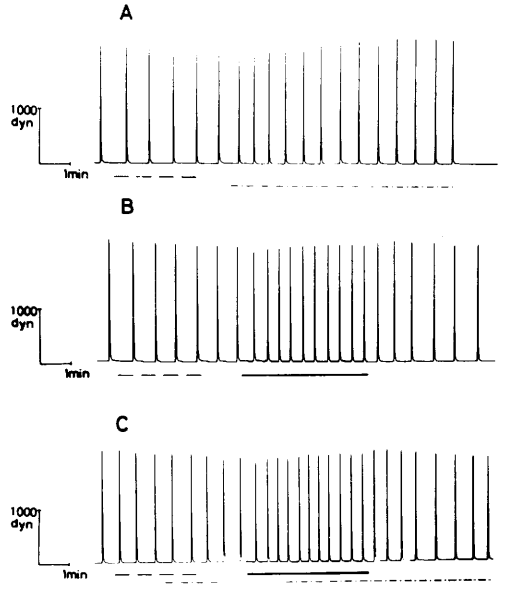

FIG. 3. Difference in stimulating effect on the ureter between noradrenaline (NA) and MV. A: Effect of NA 2×10^{-7} g/ml. B: Effect of MV (30 Hz, 100 μm). C: Effect of pretreatment with phenoxybenzamine 2×10^{-6} g/ml. The pretreatment abolished the effect of NA given after 15 min but not that of MV. The same result was obtained when these two were applied in reverse order. Broken and dark lines indicate the same items as in Figs. 1 and 2. Dot-dashed lines denote the period of NA administration.

contractions were never formed into such an incomplete tetanic wave as shown in Fig. 1C, even at the highest rhythm attainable by the stimulation. Quantitative estimation of the effect of microvibration was often more difficult in the portal strip than in the ureteral, since the contractions of the former were more irregular in rhythm and less uniform in magnitude than those of the latter. After-contractions were less marked in the former. The incidence of after-contractions was almost 100% in the ureter but was only 35% in the portal vein.

The effect of noradrenaline on both of these strips were similar in appearance to that of microvibration (Figs. 3A,B). Namely, the drug also elicited or accelerated their spontaneous activity. The similarity may suggest the possibility that microvibration stimulates the local adrenergic mechanism which in turn releases noradrenaline. If this were the case, an α-sympathetic blocking agent would prevent the visceral smooth muscle from responding to microvibration. However, this possibility could be ruled out, because pretreatment of the strips with phenoxybenzamine abolished the effect of noradrenaline but not the effect of microvibration (Fig. 3C).

No observations, except the following two, have so far been reported on the effect of vibration on spontaneous activity of the vascular and ureteral smooth muscles. Jarriault and Berthoz (1) applied vibration on the surface of the *in situ* kidney of cats and observed an induced increase in spontaneous electrical activity of the ureter. The magnitude of cyclic strains imposed upon the ureter was unknown in their experiment, and no record was made of the mechanical activity.

Ljung and Silvertsson (2) examined the effect of vibration in the isolated portal vein of rats and obtained the result that the magnitude of each spontaneous contraction was reduced to some 15% of control level without changing the pattern of activity. The vibration they used was 200 Hz in frequency and 500 μm in amplitude, corresponding to the cyclic strain of 10–15%. In our study, on the other hand, the principal effect of microvibration was an acceleration of rhythmicity not necessarily accompanied with a reduction in contraction height. The discrepancy between our findings and those of these authors may lie in differences in magnitude and frequency of imposed cyclic strains. The vibratory movements at a high frequency of larger amplitude than a critical level may produce an increase in destruction rate of the crosslinks between contractile proteins in smooth muscle which leads to a decrease in tension development. Further work needs to be done for elucidating the mode of the facilitating action of microvibration.

Summary. Spontaneous contractions were elicited by the vibration of small amplitude (microvibration) imposed upon the quiescent strips prepared from the ureter and portal vein of dogs. An acceleration of the existing rhythm in the spontaneously contracting strips was also brought about by microvibration. Frequencies and amplitudes of microvibration ranged from 1 to 90 Hz and from 50 to 150 μm, respectively. Imposed cyclic strains were less than 1% at their maximum. Up to the amplitude of 150 μm, the greater the amplitude, the faster the induced rhythm. Stepwise increase of the frequencies up to 30 Hz brought about a gradual acceleration of rhythmicity. At frequencies of above 30 Hz, no appreciable frequency-dependent differences were observable among the responses induced. Local adrenergic mechanism proved to have nothing to do with these effects.

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Received May 23, 1975. P.S.E.B.M. 1976, Vol. 151.