OESTROUS VARIATIONS OF UTERINE ACTIVITY IN THE RAT

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The oestrous variations of the uterine activity in the rat and other animals have been studied by various workers.

Blair (1, 2) measured the frequency of the contractions of isolated uteri from rats at various stages of the oestrous cycle, and found that there was no certain variation in the total number of contractions per hour, but that, in virgin rats, the number of powerful contractions was greater during dioestrus than during oestrus. Keye (3) studied isolated strips of pigs' uteri, and found that these showed infrequent powerful contractions during oestrus, and frequent small contractions during dioestrus. Secking (4) found that isolated Fallopian tubes of pigs showed frequent rapid small contractions during oestrus, and infrequent large contractions during dioestrus.

It is a well known fact that the isolated uterus from a virgin guinea pig during oestrus is useless for pituitary standardization owing to the tendency to give large spontaneous contractions, whereas the uterus from a guinea-pig in dioestrus gives much smaller but more frequent contractions.

The authors made experiments to determine the nature of the variations in the activity of the rat's uterus during the oestrous cycle. The stage of oestrus was determined by the method described by Long and Evans (5). Experiments were made first upon virgin rats (nos. Aa to An) and later upon parous rats (series B, C and D).

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The movements of uteri were studied both in situ and after isolation. Isolated uteri were suspended in oxygenated Locke's fluid at 37°C. (composition of Locke's fluid per cent NaCl 0.9, KCl 0.042, $CaCl_2$ 0.024, $NaHCO_3$ 0.05, Glucose 0.5.).

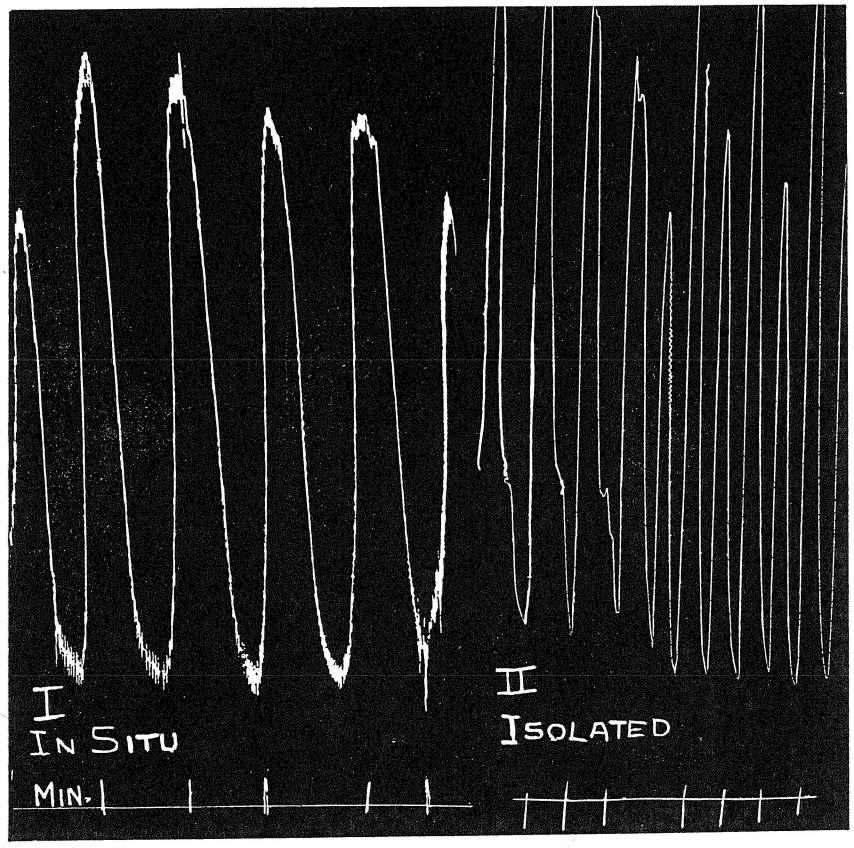

FIG. 1. MOVEMENTS OF SAME UTERUS (1) IN SITU AND (2) ISOLATED

Rat Ad. Virgin. End of Oestrus. Stage 4. In this and subsequent figures the upstroke represents contraction, the tracings read from left to right, and the time is in minutes.

Usually the movements of the whole uterus were recorded, but in some experiments the rate of conduction of the contraction in the uterus was measured by pinning the uterus on a piece of cork immersed in Locke's fluid, and recording the movements of three or four points simultaneously. In these latter cases

the uterus was connected to light levers and the movements of the levers were recorded optically on bromide paper.

The movements of the uterus in situ were recorded as follows. Rats were anaesthetized with sodium luminal (0.02 gram per 100 grams body weight given subcutaneously). The abdomen was opened in the mid line from sternum to pubis and the abdominal walls were held up by hooks to form a container, and the abdominal cavity was filled with warm Locke's fluid. The animal was kept warm by being placed on a warm electric hot plate (heated to 40°C.), and a carbon filament lamp was placed a little above the open abdomen. The uterine movements were recorded by threads attached to light writing levers, and when it was desired to record the movements of the two ends of the uterus simultaneously the center half of the uterus was fixed by a wire snare.

THE NORMAL MOVEMENTS OF THE RAT'S UTERUS

In a number of cases the movements of the uterus in situ were first recorded and then the animal was killed and the movements of the isolated uterus were recorded. Figures 1 and 2 show examples of the records obtained. These figures show that the rat's uterus in situ actually performs movements similar in amplitude to those observed in the isolated condition. Table 1 shows the frequencies observed in situ and in the isolated uterus, and inspection of this table at once shows that the frequencies observed in the isolated uterus only give a rough indication of the frequency of the contractions in situ.

The movements of the rat's uterus both in situ and isolated appear at first sight to be fairly regular but a study of a number of tracings showed that curious alterations in frequency such as is shown in the isolated uterus in figure 1 often occurred. Moreover the alternation of large and small contractions that is shown in figure 2 was also common. These facts rendered it impossible to make any accurate estimation of the frequency of the uterine contractions in a large number of cases. Experiments were made therefore to determine the laws governing the origin of the contractions in the uterus.

ORIGIN OF UTERINE CONTRACTIONS

The rhythm of the uterus was found to be always irregular. For example the uterus in situ in figure 1 contracted with exceptional regularity but even in this case the intervals between

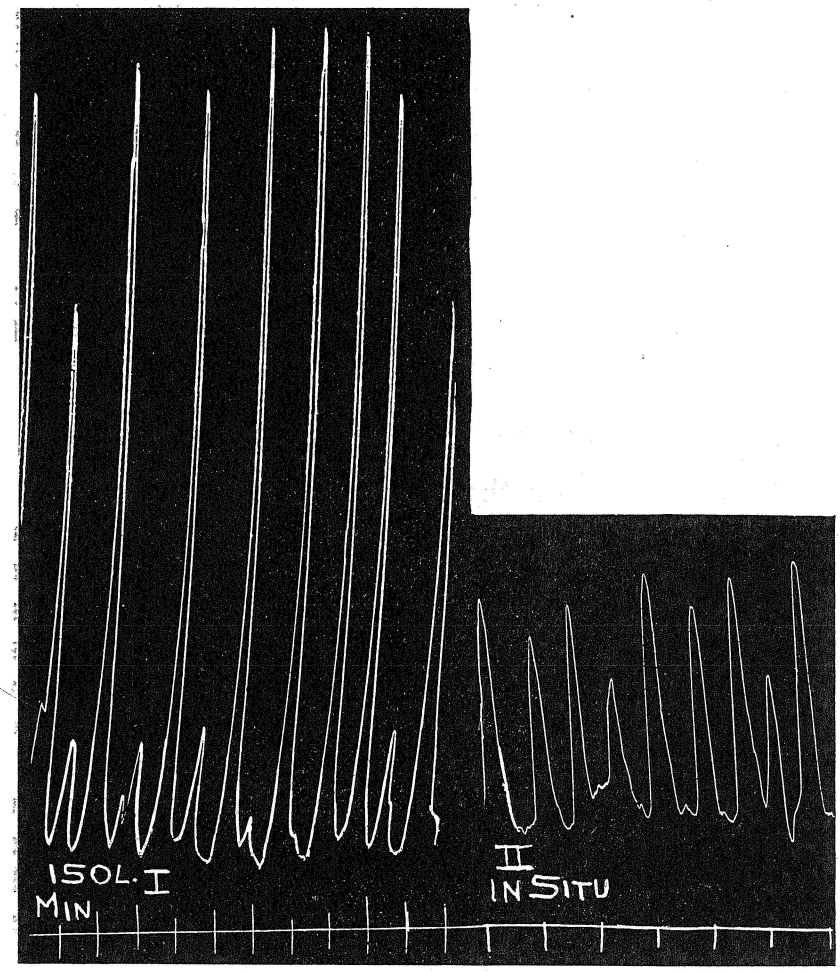

FIG. 2. MOVEMENTS OF THE SAME UTERUS (1) ISOLATED AND (2) IN SITU
Rat Ah. Virgin. Stage 2.

successive contractions varied from 25 to 41 seconds, the average interval being 33 seconds.

Observation showed that the contractions usually started at the ovarian end of the uterus and passed downwards, and

when the ovarian end was cut off the remainder of the uterus contracted with a diminished frequency. The effect on the frequency of contractions of cutting off successive portions from the ovarian end of the uterus is shown in table 2.

All portions of the uterus therefore show rhythmic contractions but the natural frequency is greatest at the ovarian end. The site of origin of the uterine contractions in isolated uteri was next examined by taking simultaneous records of the con-

TABLE 1

Frequency per hour of uterine contractions

	VIRGIN RATS					PAROUS RATS					
Number of rat	Ad	Ah	Aj	An	Ap	Bc	Be	B	Bg	Bi	C_{13}
Uterus in situ	100	85	78	110	84	105	100	96	60	60	96
Isolated uterus	72	72	50	72	80	90	90	120	58	76	120

TABLE 2

The effect on the frequency of contractions in the isolated uterus of cutting off successive portions of the ovarian end

	FREQUENCY PER HOUR	
	Rat Ad	Rat An
Whole uterus	70	90
Ovarian quarter removed	45	60
Ovarian half removed	45	60
Vaginal quarter	20	40

tractions of different points along the uterus. In some cases it was found that the contractions all started from the ovarian end and passed right down the uterus but in other cases conduction was poor and the contractions starting at the ovarian end tended to die out about the middle of the uterus, and in these latter cases contractions originated all over the uterus. The calculated site of origin of six successive contractions is shown in figure 3.

This variation in the site of origin of contractions is sufficient to account for many of the irregularities observed in the uterine contractions.

CONDUCTION OF CONTRACTIONS

The two types of good conduction and poor conduction have been mentioned, and in some cases intermediate types were observed in which contractions were for some time conducted down the length of the uterus, and then a change occurred and the ovarian and vaginal ends contracted independently (cf. fig. 4). In some cases however the ovarian and vaginal ends contracted entirely independently at quite different rates.

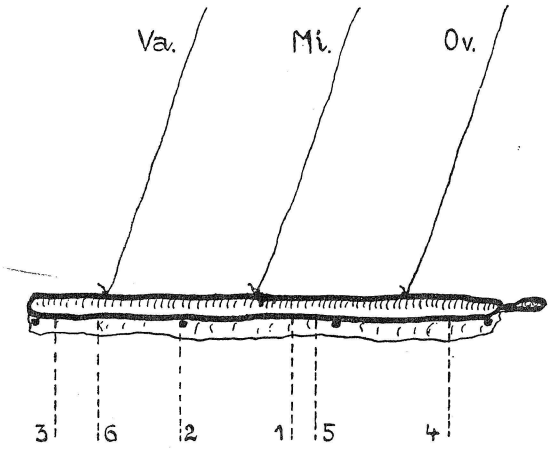

FIG. 3. DIAGRAM SHOWING METHOD OF RECORDING CONTRACTIONS OF UTERUS FROM THREE LEADS SIMULTANEOUSLY

The figures 1 to 6 show the sites of origin of six sucessive contractions. Uterus from rat in dioestrus.

VARIATIONS IN CONDUCTION AND THE STAGE OF OESTRUS

We found that the conduction of contractions in the rat's uterus was profoundly affected by the stage of the oestrous cycle. During oestrus conduction was found to be good and the usual picture was that of powerful contractions commencing at the ovarian end and sweeping relatively rapidly down the whole length of the uterus (cf. figs. 1, 2, and 5).

During dioestrus the conduction was poor and the contractions starting at the ovarian end usually died out about the middle of the uterus, and the vaginal end of the uterus contracted independently of the rest of the uterus (cf. figs. 4

and 5). This difference was observed both in uteri in situ and in isolated uteri as is shown in tables 3 and 4.

THE RELATION BETWEEN FREQUENCY OF RHYTHM AND THE OESTROUS CYCLE

It is obviously difficult to compare the frequency of contractions in oestrus and dioestrus, since in the latter condition the

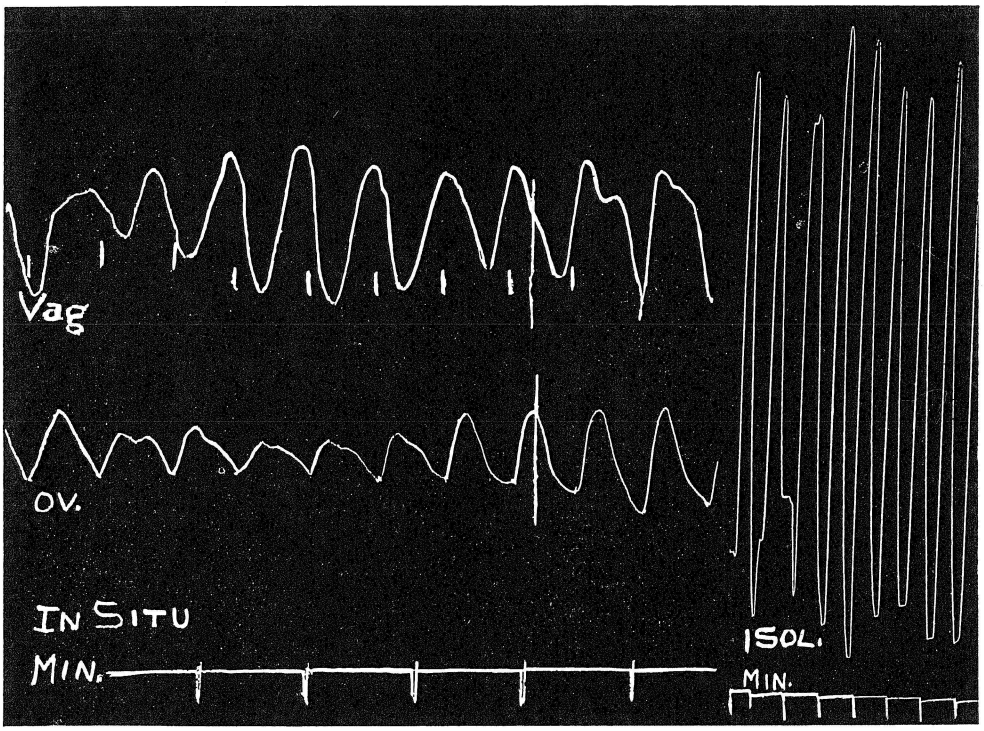

FIG. 4. MOVEMENTS OF SAME UTERUS IN SITU AND ISOLATED

Rat An. Virgin. Dioesttus. Stage 5. The movements in situ were recorded simultaneously from the ovarian and vaginal ends. The tracing shows that the movements were at first conducted from one end to the other, with an interval of 10″ to 15″; after the sixth contraction the vaginal end contracted independently of the ovarian end.

different portions of the uterus are contracting independently and at different rhythms.

We were unable to detect any certain influence of the oestrous cycle on the frequency of contractions. The results observed

TABLE 3

The conduction of waves of contraction in the isolated uterus of the rat

	STAGES OF OESTRUS										
	II–III (Mid-oestrus)				IV (Late oestrus)		V (Dioestrus)				
Number of experiment	D_2	D_3	D_8	D_9	D_5	D_{12}	D_1	D_4	D_{10}	D_{11}	D_{13}
Rate of conduction, millimeters per second	6	6.3	3.3		3.5	3.6	3.6	1.0	3.3	2.2	3.3
Frequency per hour of contractions:											
(a) Ovarian end	120	60	54	72	60	70	150	60	87	88	96
(b) Vaginal end	120	60	54	72	60	70	150	48	67	72	78
The distance over which the contractions were conducted	In all cases the contractions were conducted throughout the length of the uterus.						In all cases but one (D_1) the two ends of the uterus contracted independently.				

TABLE 4

The conduction of waves of contraction in the rat's uterus in situ

	STAGE OF OESTRUS									
	II–III (Mid-oestrus)				IV (Late oestrus)		V (Dioestrus)			
Number of rat	Ah	C_3	C_6	Be	C_4	C_5	C_1	C_2	C_{22}	An
Rate of conduction, millimeters per second	3.3	5	—	2.5	—	—	—	—	—	3.3
Frequency per hour of contractions:										
(a) Ovarian end	85	65	99	100	93	98	135	130	144	120
(b) Vaginal end	85	65	66	100	73	67	90	116	84	120

are summarized in table 5. The salient feature of this table appears to be the great individual variation in the frequencies observed.

THE UTERINE MOVEMENTS DURING PREGNANCY

The pregnant uterus showed powerful contractions which were conducted rapidly throughout the length of the uterus

(cf. figure 5). The uterine movements appeared to increase in frequency during pregnancy, and during the third week of week of pregnancy frequencies of 120 and 144 contractions per hour were observed in two cases. The fact that these extensive tonic contractions occur continuously throughout pregnancy shows that these movements cannot exert much affect upon the contents of the uterus.

TABLE 5

The frequency of contractions of the rat's uterus (contractions per hour)

	VIRGIN RATS		PAROUS RATS	
	Isolated uterus	Uterus in situ	Isolated uterus	Uterus in situ
Stage I*		70		68
				80
				90
Stages II and III	120		120	100
	90	100	90	98
	72	85	72	92
			60	66
	70		54	
Stage IV	80	84	120	96
		70	114	
		70	70	
			60	
Stage V (Dioestrus)	120	100	156 88	144
	110		150 87	136
	90		144 76	120
	72		120 76	90
	72		104 60	90
	65		100 54	80
	60		96 50	60
			90	60

* The stages are those described by Long and Evans (5).

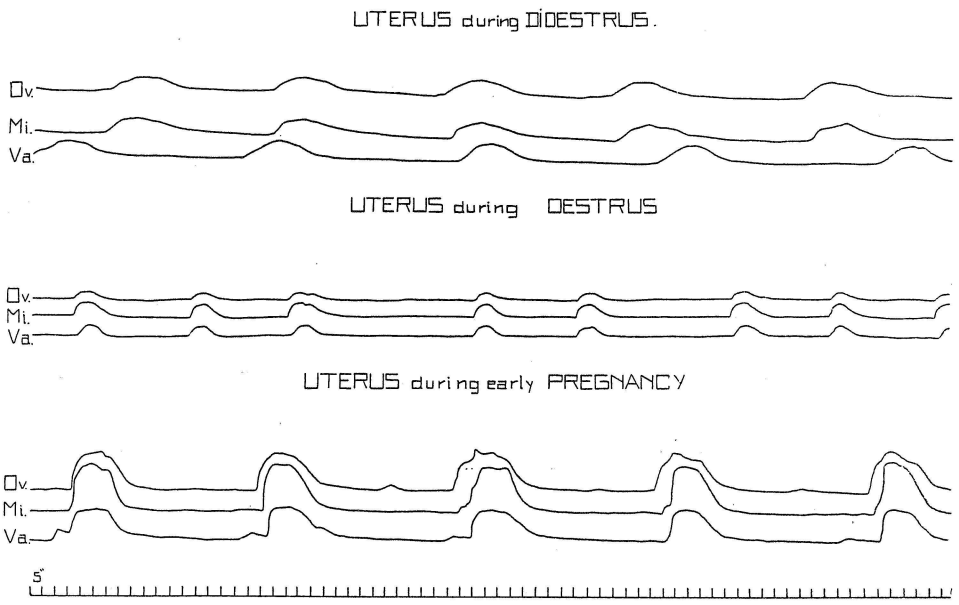

FIG. 5. RECORDS OF THE MOVEMENTS OF THREE DIFFERENT ISOLATED UTERI

In each case simultaneous records were taken of the movements of the ovarian end, the middle, and the vaginal end of the uterus. The lever movements were recorded optically. *Upper tracing:* Uterus during dioestrus. The ovarian end and middle contracted in sequence. Conduction interval 3 seconds. The vaginal end contracted independently. *Middle tracing:* Uterus in oestrus (Stage 2) Contractions passed rapidly down whole uterus. *Lower tracing:* Uterus in second week of pregnancy. The contractions passed rapidly down the whole uterus.

DISCUSSION

Engelmann (6) in his classical paper on the movements of the ureter showed that the rate of conduction of peristaltic waves in the ureter was greatly diminished directly after the passage of a contraction and did not return to normal until nearly twenty seconds. He also found that exposure to cold diminished the rate of conduction in the ureter, and that when the ureter was conducting poorly the peristaltic waves tended to die out during their passage down the ureter.

Our experiments show that the behavior of the uterus is largely determined by its powers of conduction. Conduction is best during oestrus and pregnancy, but even then does not exceed 10 mm. per second, which is less than the rate of con-

duction in the ureter. During dioestrus the conduction rate falls to less than one third of this figure and usually the contraction waves starting at the ovarian end die out midway down the uterus, and the vaginal end assumes an independent rhythm.

The relation between rate of conduction and frequency of contractions was not measured, but there is no reason to suppose that it is different from the relation observed by Engelmann in the ureter. The regular movements of the rat's uterus at first sight appear to offer a marked contrast to the irregular movements observed in the uterus of the rabbit and cat. The regularity is due to the frequency of the contractions being low and the conduction fairly good so that the contractions starting at the ovarian end usually pass down the greater portion of the uterus. Independent contractions in the two ends of the uterus are however frequently observed, and if the conduction became a little worse, or if the spontaneous rhythm of the uterus became quicker, the result would be independent contractions in several places in the uterus, a condition which would resemble the state of affairs normally occurring in the rabbit.

CONCLUSIONS

1. The rate of conduction of waves of contraction in the rat's uterus varies considerably, it is rapid during oestrus and pregnancy and slow during dioestrus.

2. During oestrus and pregnancy the waves of contraction usually pass down the whole uterus.

3. During dioestrus the waves of contraction tend to die out and in consequence the two ends of the uterus usually contract with independent rhythms.

4. No certain relation was observed between the frequency of contractions and the stage of oestrus.

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