An inexpensive meter to measure differences in electrical resistance in the rat vagina during the ovarian cycle

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Ramos, S. D., J. M. Lee, and J. D. Peuler. An inexpensive meter to measure differences in electrical resistance in the rat vagina during the ovarian cycle. J Appl Physiol 91: 667–670, 2001.—The inherent electrical resistance of the rat vaginal wall rises markedly near the beginning of estrus and then falls again to low levels for the remainder of the ovarian cycle. Accordingly, special instruments have been developed to measure such resistances (within seconds) on simply inserting a small probe fitted with a pair of recording electrodes into the vagina (i.e., the MK-10A impedance checker and the EC40 estrus cycle monitor). As described herein, these two instruments are far more convenient for monitoring individual cycles than more laborious methods in which vaginal smears are inspected for changes in numbers of cornified (C), nucleated (N), and leukocytic (L) cells. However, they are also expensive and their use has essentially remained uncited in the literature. Thus we sought to determine whether a simple, inexpensive electrical meter (with resistance-measuring capacity), as commonly used by professional electricians, would serve the same purpose. We chose a standard multifunctional meter (model 22-178, RadioShack) and attached leads to it fabricated from the internal wiring of a shielded audiocable (model 42-2387A, RadioShack), one male terminal of which was used as a vaginal probe. In rats from which vagina smears revealed cell numbers in the order of C ≥ N > L (typical of early estrus) electrical resistances were high, 488 ± 130 kΩ (18 rats). In rats from which vagina smears revealed all other possible cell distributions, electrical resistances (combined) were much lower (P < 0.05), 124 ± 23 kΩ (32 rats). Thus readily accessible, inexpensive electrical meters may be useful in assessing the status of estrus in female rats, either to improve reproductive efficiencies and/or for other purposes involving experiments in which such information is desirable.

METHODS

Animals. Sexually mature female Sprague-Dawley rats (~250–300 g) from Harlan (Indianapolis, IN) were used in the two studies (plus preliminary work) described below. All were fed food (standard rat chow) and water ad libitum under a 12:12-h light-dark cycle. They were all housed individually in solid plastic cages (46 × 23 × 20 cm; with 46 × 23-cm wire grid tops) containing heat-dried, ground corncob as bedding, which was changed weekly. This type of individual housing was maintained for at least 4 wk in a well-ventilated room (≥10 fresh-air changes/h) before experimentation in an attempt to randomize the rats’ ovarian cycles (7, 8). In addition, a number of them were ovarioctomized at least 2 wk before use in the second study. Except in a few instances, all rats were lightly anesthetized with ketamine (40 mg/kg) and xylazine (4 mg/kg) given intraperitoneally immediately be-

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fore experimental use to satisfy animal care-and-use concerns that might arise in an initial project of this type.

**Instrumentation.** To measure the inherent electrical resistance of the inner lining of the vaginal wall, we chose to use one of several typical digital multimeters commonly employed by professional electricians to measure resistances (as well as voltages and currents) in various types of electrical circuits. The meter we chose (model 22-178, RadioShack, Fort Worth, TX) is portable, battery operated, and measures resistances over a wide range, from ohms to megohms with an accuracy of $\pm 1\%$ at the kilohm level. Yet, it is only a small fraction of the total cost required to purchase one of the two currently available special instruments described above in the Introduction. For a vaginal probe, we used one of the male terminals (plugs) of a typical inexpensive shielded audiocable (model 43-2837A, RadioShack), the internal wiring of which was cut and fitted with solderless banana plugs to allow contact with the meter. Each terminal consists of three smooth-metal conductors separated by two rings of nonmetallic material serving as isolators (Fig. 1). Preliminary experiments revealed that, of these three conductors (shown in Fig. 1 as the tip, middle, and base of the terminal), electrical resistance values for the inner vaginal wall recorded between the middle and base were the most stable over time (several seconds) after insertion of the terminal into the vagina. Thus this combination was used in all subsequent studies. Furthermore, stability of resistance readings appeared to be influenced very little by the order in which the cable wiring (leads) from the middle and base segments of the terminal were connected to the negative and positive jacks of the meter. However, in all the experiments described below, the banana plug for the base lead was always plugged into the negative jack (the center jack of the 3 on the meter) and the banana plug for the middle lead was always plugged into the positive jack (the jack on the right side of the meter). A third jack on the meter (left side) was never used because it is not intended for resistance measurements.

**Studies.** Two studies were performed, one in which the relationship of vaginal electrical resistance measurements to vaginal smear cell numbers was examined in sexually mature female rats. In smears in which the major cell type was nucleated (54 $\pm 3\%$), the remaining cells were 30 $\pm 3\%$ cornified and 15 $\pm 3\%$ leukocytic. In smears in which the major cell type was cornified (58 $\pm 3\%$), the remaining cells were 29 $\pm 2\%$ nucleated and 13 $\pm 2\%$ leukocytic. In smears in which the major cell type was leukocytic (58 $\pm 3\%$), the remaining cells were 27 $\pm 2\%$ nucleated and 15 $\pm 2\%$ cornified.

In our first study, we found that the inherent electrical resistance levels of the inner vaginal wall as measured with the meter described in METHODS were clearly highest in those rats in which the major vagina smear cell type was C, as opposed to either N or L (Fig. 2). In addition, if these same rats were further separated according to the complete order of vaginal smear cell numbers, then the highest resistance levels were limited to those in which that cell order was C, as opposed to either N or L (Fig. 2). In addition, if these same rats were further separated according to the complete order of vaginal smear cell numbers, then the highest resistance levels were limited to those in which that cell order was C, as opposed to either N or L (Fig. 2). In addition, if these same rats were further separated according to the complete order of vaginal smear cell numbers, then the highest resistance levels were limited to those in which that cell order was C, as opposed to either N or L (Fig. 2).
In our second study, we found that the same meter also detected the marked lowering of vaginal wall resistance levels known to occur with ovariectomy in the sexually mature female rat (Fig. 4). We did not collect smears from the control rats with intact ovaries in this study. Control rats were simply selected at random from individually housed rats at the same time that we measured resistances in the ovariectomized rats. However, the low average resistance level of the ovariectomized rats (Fig. 4) is also notably less than any of the three average resistance levels of the rats from our first study in which smears were collected and inspected (shown in Fig. 2). In addition, resistance readings from a few conscious rats in this second study did not differ significantly from readings recorded in the same rats under light anesthesia (the latter readings equaled 97 ± 2% of the conscious readings, n = 6 rats).

DISCUSSION

The main findings from these experiments are as follows. First, in sexually mature female rats from which vaginal smears revealed cell numbers in the order of C > N > L (typical of early estrus), electrical resistances of the vaginal wall as measured by a commonly used inexpensive multimeter were much higher than in rats from which smears revealed N or L cells as the major cell type, or even cell numbers in the order of C > L > N (typical of late estrus). Second, ovariectomy, which has been shown previously to markedly reduce vaginal wall electrical resistance levels (4), did so as well in another study from this work as detected by the same meter. In addition, vaginal wall resistance measurements recorded in a select number of rats were not influenced by whether the animals were conscious or anesthetized. Thus readily accessible, ready-to-use, inexpensive electrical meters may be useful in assessing the status of estrus in female rats either to improve reproductive efficiencies and/or for other purposes involving experiments in which such information is desirable.

There are three topics related to this work that should be discussed in some detail.

Fig. 3. Sample photomicrographs from stained vagina smears in which the major cell type was either nucleated (A), cornified (B), or leukocytic (C). Original magnification ×40.

Fig. 4. Effects of ovariectomy on vaginal wall electrical resistance measurements (obtained via the meter described in METHODS) in sexually mature female rats.
First, the audiocable terminal employed as a vaginal probe in these experiments consisted of potentially three electrical conductors, illustrated in Fig. 1 from left to right as the tip, middle, and base of the terminal. As described in METHODS, preliminary experiments revealed that the stability of the vaginal wall resistance values was best when recorded between the base and middle conductors. The most likely reason that resistances were less stable when recorded with the tip (either tip to middle or tip to base) may relate to its irregular shape. Unlike the middle or base, the tip is not perfectly cylindrical but rather partially indented (Fig. 1). Thus contact of the tip with the vaginal wall could conceivably vary enough from moment to moment to influence resistance readings, especially if the smooth muscle of the wall should intermittently contract and relax at various times during the measurement.

Second, electrical resistance values for rat vaginal tissue as measured in the present work were much higher overall than those reported previously by others (1, 3, 4). This may be due to a specific difference in the electrical characteristics of the RadioShack instrument used in the present study compared with the instruments used in the previous studies. In particular, it may relate to the manner in which current is applied to the tissue from these instruments. To be capable of measuring the inherent resistance of any electrical circuit, an instrument must be able to deliver at least a small current to the circuit under a controlled voltage. For the meter used in the present work and all those used previously by others to measure tissue resistances in live subjects (1–5, 9), such currents and voltages are very low (i.e., in microampere and millivolt ranges). They are not capable of exciting the tissues and/or being sensed by the subjects (9). However, the meter in this work (and any similar device that is commonly used by professional electricians) only delivers such current in one direction. All the other instruments previously used by the other above-mentioned laboratories to measure vaginal wall resistances (1–5) deliver a rapidly oscillating (alternating) current. Conceivably, tissue resistance to the passage of such current may be lower than when the current is only moving in one direction.

Third, results from this work also differ from those reported by the other laboratories studying rats in terms of when, within the ovarian cycle, the highest resistance values occur. As measured by the RadioShack meter in the present experiments, the highest resistances were linked to vaginal smear data associated mainly with early estrus, i.e., when the smear cell order is clearly C > N > L. Previously, others had reported peak resistances in rats even earlier, during proestrus (1, 3, 4), presumably when they found smears containing mostly nucleated cells. Although smear data were collected in those studies, actual cell numbers and related interpretations were not clearly presented (1, 3, 4). However, two other laboratories have reported similar differences in the location of peak electrical resistance values for vaginal tissue in guinea pigs (2, 5). In the first, peak resistances were said to occur in proestrus (2). Unfortunately, the actual vaginal smear data for the guinea pigs used in that study were not revealed (2). In a later (second) guinea pig study in which all smear cell data were presented in considerable detail, peak resistances occurred later than proestrus, indeed, well into late estrus (5). Although the primary instrumentation used to measure resistances in these two guinea pig studies was essentially the same, one noteworthy difference was discussed by the second group of investigators in terms of the distance separating the recording elements of the vaginal probes employed. This distance was only 1 mm in the second study (5) compared with 6 mm in the first (2). It is difficult to appreciate how a difference in this distance might influence when, within the ovarian cycle, peak resistances might be detected in the guinea pig vagina. However, it is precisely this same difference that separates the findings of the present experiments from all the previous results with rats discussed above (1, 3, 4). For the probe used in the present experiments (with rats) the distance separating the recording elements (middle to base sections of the terminal illustrated in Fig. 1) was even somewhat less than 1 mm, whereas in all the other rat studies (in which peak resistances were reported to occur in proestrus) that distance was typically 3–4 mm (1, 3, 4).

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