BRIEF NOTE

IMPEDANCE PNEUMOGRAPHY IN MICE: ELECTRODE DESIGN AND THE EFFECT OF ELECTRODE LOCATION[1]

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We were interested in using the impedance technique for the measurement of respiration in mice. In the initial phase of our studies, we employed stainless-steel needle electrodes, which are commonly used in recording electrocardiograms from small anesthetized mammals. However, heavy anesthesia was necessary and proper electrode placement was difficult. Another type of electrode, the silver-silver chloride, liquid-junction type, has been used for both electrocardiography and impedance penumography on large mammals by other investigators (Rowley *et al* 1961; Lucchina and Phipps 1963; Day and Lippitt 1964; Geddes *et al* *al* 1967; Geddes *et al* 1968). We fabricated a silver-silver chloride, liquid junction electrode which permitted the use of a light level of anesthesia with impedance pneumograms free from movement artifact and baseline shift, and electrode placement without undue stress to the mouse.

Electrode location affects transthoracic respiratory impedance measurements (Reviewed by Baker and Geddes 1970). Although the changing volume of air in the lungs accounts for much of the impedance signal, other current pathways alter the recorded event. Diaphram movement has been shown to contribute significantly to the respiratory impedance signal (ΔZ) when recordings are made along the midaxillary lines at the xiphoid level. A better correlation between ΔZ and tidal volume has been found when ΔZ was recorded at a higher level on the thorax.

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ELECTRODE DESIGN

A length of plastic coated stranded hook-up wire was soldered to the center of a silver foil square (fig. 1). An electrode support was punched from a sheet of flexible plastic and attached to the silver foil electrode with contact cement. To provide electrical isolation, the entire

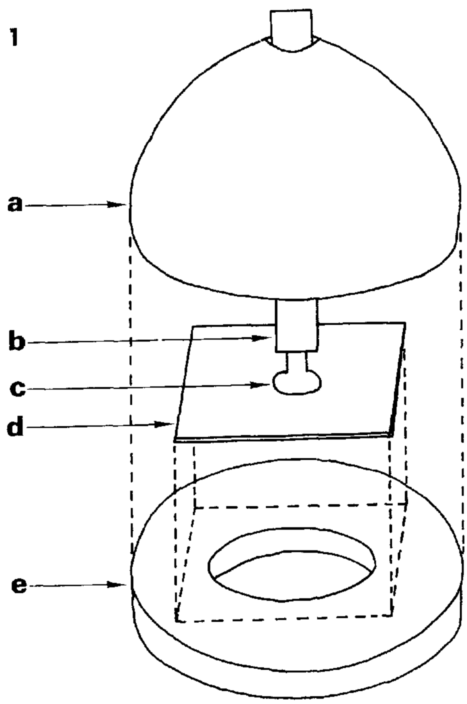
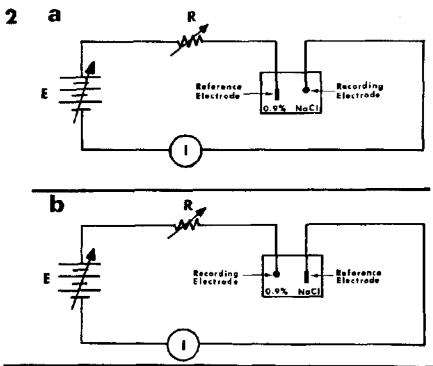


FIGURE 1. Exploded diagram of the silver-silver chloride, liquid-junction electrode. Key: a) silicone rubber electrical isolation, b) plastic coated wire (15 inch, 32 AWG), c) solder joint (tin/lead ratio=60/40), d) silver foil ($\frac{3}{16}$ inch square), and e) flexible plastic support (0.25 inch O.D., 0.125 inch I.D., thickness, 0.02 inch).

lead-electrode-support assembly was covered with silicone rubber. Double-sided adhesive discs were used to attach the electrodes to the mouse. These were punched from standard, commercially available, ECG adhesive discs.

Bare silver electrodes exhibit an increase in impedance when they are exposed to electrode paste, moist skin, or a saline solution. This increase in impedance is due to a chloriding of the silver electrodes. Since changes in electrode impedance cause DC baseline shifts, it was necessary to electrically stabilize the recording electrodes. This was done by heavily chloriding the silver electrodes. Cleaning and chloriding procedures were adopted from Geddes *et al* (1969). Each recording electrode was electrically cleaned by making it negative with respect to a silver wire reference electrode (D = 0.075 inch; L = 1.0 inch). Both electrodes were submerged in 100 ml of 0.9% NaCl and placed in series with a variable power supply, a resistance substitute box, and a milliammeter (fig. 2a). Voltage and resistance were adjusted to provide a 10 ma current for 5 minutes. To chloride the recording electrode, it was made positive with respect to the silver-wire reference electrode (fig. 2b). A current of 1.42 ma for 210 seconds produced a chloride deposit of 4,200 ma·sec/cm^2. Although this chloride deposit was higher than that suggested by Geddes *et al* (1969) for bioelectric events (100–500 ma·sec/cm^2), our recording electrodes were extremely stable and could be used on several mice before rechloriding was necessary. The impedance of a cleaned pair of electrodes in saline was 288 ohms while a chlorided pair of electrodes had an impedance of 596 ohms when using a 4μA rms current at 50kHz.



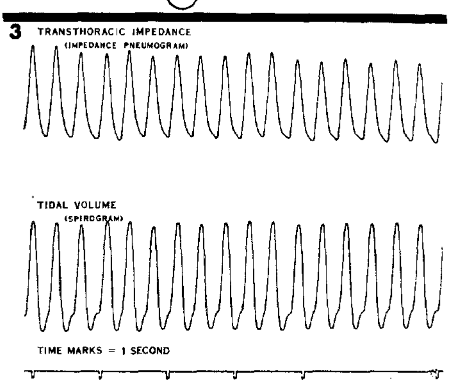


FIGURE 2. Schematics for cleaning and chloriding the electrode. Key: a) cleaning schematics, and b) chloriding schematic. NOTE: *Reversal of electrode potentials.*

FIGURE 3. Simultaneous recordings of the impedance penumogram and spirogram in a 90-day-old C57BL/6 mouse. NOTE: *An upward deflection indicates inspiration.*

A sample tracing of simultaneously recorded transthoracic impedance change and tidal volume of a 90 day old C57BL/6 mouse is shown in figure 3. Recordings were made on a medium-frequency, ink-writing recorder (Physiograph DMP-4A, Narco Bio-Systems, Houston, TX). Electrode placement was along the midaxillary lines at the level of the xiphoid process. Respired volume was measured directly with a manometric microspirometer (Williams 1971).

EFFECT OF ELECTRODE LOCATION

Electrode location has a gross effect on the measurement of transthoracic impedance, as shown in figure 4. Recordings were made with a commercially available, bipolar impedance pneumograph (Narco Bio-Systems) on a 90-day-old C57BL6 male mouse. The effect demonstrated in this figure has been observed with mice of all ages and also has been demonstrated with human subjects in our laboratory. In the upper tracing (fig. 4a), transthoracic impedance increased with inspiration when the electrodes were placed at the level of the xiphoid process along the midaxillary lines. The bottom tracing (fig. 4b) shows a recording made on the same mouse but with the electrodes placed less than a centimeter below the xiphoid process. Transthoracic impedance then decreased with inspiration. A decrease in impedance with inspiration has been observed by some investigators (Allison *et al* 1964; Logic *et al* 1967; Naifeh *et al* 1970), but there appears to be a lack of information regarding the origin of this phenomenon or its validity in tidal volume measurement.

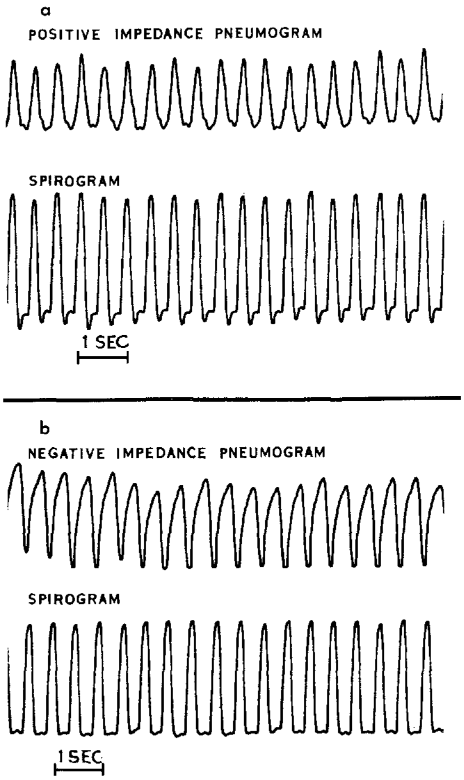


FIGURE 4. Effect of electrode location on the polarity of the impedance penumogram. a) "Positive Impedance Pneumogram"—transthoracic impedance increases with inspiration with electrodes at xiphoid level b) "Negative Impedance Pneumogram"—transthoracic impedance decreases with inspiration with electrodes below xiphoid level.

Since there has been very little description of this phenomenon, we adopted the following terminology. The occurrence of a decrease in transthoracic impedance with inspiration will be called, "Reversal of Impedance." To indicate the polarity of the impedance change with inspiration, the graphic record of a decrease in impedance with inspiration will be referred to as a "Positive Impedance Pneumogram." When recording respiration from large animals the "Reversal of Impedance" is usually not a problem. This is due to the large physical size of the subject's thorax with respect to the electrode size. A smaller ratio of thorax to electrode size increases the chances of obtaining a "Negative Impedance Pneumogram."

We believe that debate about the origin of the respiratory impedance signal is further complicated by the above observation. A decrease in impedance at the thoracic-abdominal border could be obtained with the movement of a low-resistance mass into the measuring field. Gross anatomical considerations include contraction of the diaphram so that it is parallel with the field of measurement, and movement or re-orientation of upper abdominal structures with low resistivity (such as the liver) into the measuring field.

Since the "Negative Impedance Pneumogram" has not been shown to be correlated with tidal volume we recorded only "Positive Impedance Pneumograms" in our studies. For those investigators interested in using the electrical impedance technique to record respiration from small mammals, we urge caution in the placement of electrodes so as to insure the recording of a "Positive Impedance Pneumogram."

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