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An Easily Assembled and Inexpensive Apparatus for Continuous Monitoring of Expired Carbon Dioxide Concentrations in Artificially Ventilated Animals

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STRAHLENDORF, H , J STRAHLENDORF AND G JOHNSON *An easily assembled and inexpensive apparatus for continuous monitoring of expired carbon dioxide concentrations in artifically ventilated animals* PHARMAC BIOCHEM BEHAV 10(4) 619–621, 1979 —An inexpensive and simple apparatus for monitoring expired carbon dioxide concentrations in artificially ventilated animal preparations is described The system may be rapidly and easily constructed using a standard recording pH electrometer and a commercially available Pco_2 electrode This assembly has been proven to be an effective and sensitive means of monitoring CO_2 levels, detecting changes in this gas within one-half percentage

Electrophysiologic recordings   Carbon dioxide concentration   Artificially ventilated animals

CONTROL of ancillary parameters such as Pco_2, Po_2, blood pressure and body temperature is essential when monitoring electrophysiological endpoints [1] Specifically, neuronal excitability may be altered by local extracellular pH fluctuations determined in part by pulmonary ventilation [2] In neurophysiologic experiments, end tidal CO_2 concentration provides an accurate index for blood Pco_2 and circumvents the difficulties of blood gas analysis The expense of commercially available systems for measurement of respiratory CO_2 frequently precludes their acquisition by small laboratories interested in monitoring variables capable of changing electrophysiologic recordings Although end-tidal CO_2 concentration may not adequately reflect the blood pH spectrum in compromised lung function, it provides a valuable means for monitoring systemic acid-base balance when lung function is normal.

The following is a description of an apparatus capable of continuously measuring respiratory CO_2 in artificially ventilated preparations This apparatus operates with maximum accuracy within the physiological range of 3–5% for end-tidal CO_2 measurements In electrophysiological experiments, the investigator is only interested in ascertaining that the preparation is ventilated within the normal limits; therefore, this instrument provides a satisfactory means of obtaining this index The system may be rapidly and easily constructed using a standard recording pH electrometer, a commercially available Pco_2 electrode and a solenoid valve In the absence of the recording meter, any expanded scale pH meter may be recalibrated with gas mixtures

PRINCIPLE OF OPERATION

Direct measurement of CO_2 concentration potentiometrically is an adaptation of a pH measurement within an electrode assembly consisting of a combination pH glass and reference electrode, a gas permeable membrane and an appropriate electrolyte solution Diffusion of CO_2 across the membrane down its concentration gradient results in the formation of carbonic acid within a limited volume of electrolyte solution which is detected by the electrode system Intraelectrode pH changes proportionally reflect CO_2 concentrations, and resultant signals are fed into a recording pH meter with scale expansion.

CONSTRUCTION

An air and water tight chamber housing the electrode is constructed of plastic tubing to which is fitted inlet and outlet tubings, allowing passage of gas across the membrane of the electrode The volume of space between the tip of the electrode and the chamber housing should be kept small, preferably less than one cubic centimeter The exact dimensions of the housing will be determined by the size of the electrode employed The entire housing containing the electrode is mounted horizontally in a small water bath connected to a high quality circulating thermostat which serves to maintain the assembly at a constant temperature of 37 0°C To allow temperature equilibration of the gas entering the electrode chamber, the inlet tubing is coiled inside of the bath. (Figs. 1 and 2)

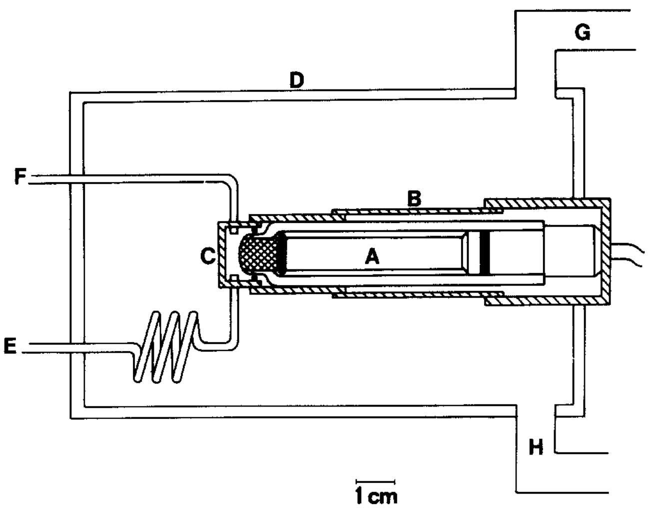

FIG 1 Detail of electrode, electrode housing, and water bath assembly (A) Pco_2 electrode assembly (B) Housing for electrode of polyethylene tubing (C) Tygon chamber surrounding electrode tip (D) Styrine box forming water bath housing (E) Inlet for air sample (F) Outlet for air sample (G) Inlet for circulating water (H) Outlet for circulating water Plastic joints are cemented and sealed with silicone caulking Air and water passages are of flexible tubing such as Tygon

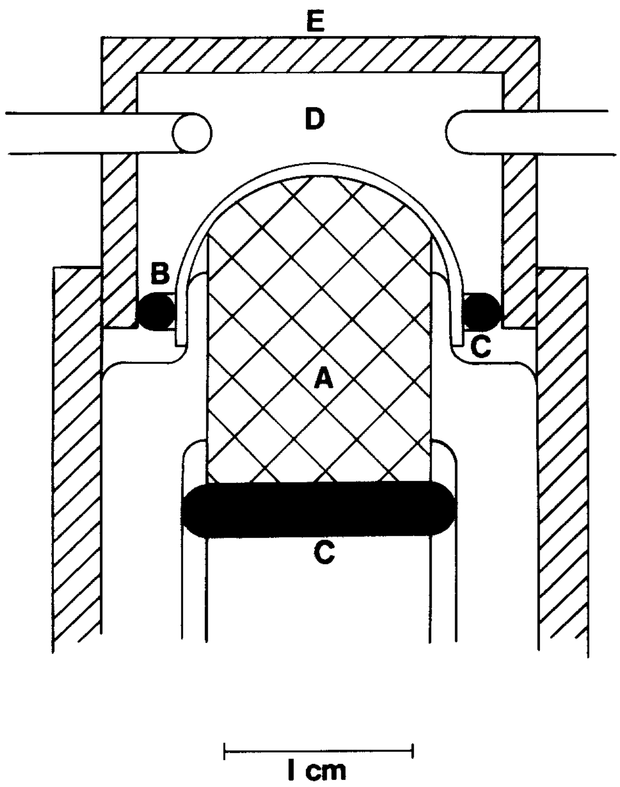

FIG 2 Enlargement of electrode tip and chamber (A) Inner membrane of nylon mesh (B) Outer gas permeable membrane (C) O-rings which secure membranes to electrode tip and serve as seal to gas diffusion chamber (D) Gas diffusion chamber (E) Tygon chamber surrounding electrode tip

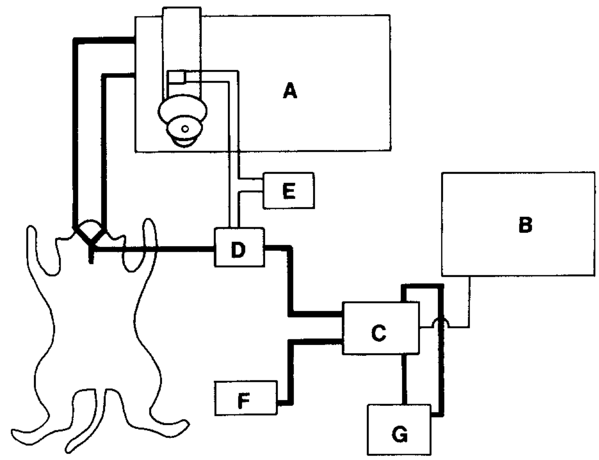

FIG 3 Operational diagram for continuous monitoring of expired air CO_2 concentrations (A) Respirator with roller switch attached in a manner which allows the solenoid valve to open during expiration (B) Recording electrometer (C) Electrode assembly (D) Solenoid valve (E) Transformer (F) Vacuum pump (G) Water bath heater-circulator Bold lines are air and water passages, fine lines are electrical connections

A sample of expired air is obtained from a side arm extension of the endotracheal tube This attachment is positioned close to the point of entry of the tube into the trachea, thereby minimizing dead space and mixing of the inspired and expired airs. A low voltage solenoid valve activated during the expiration stroke of the Harvard respirator by a microroller switch positioned over the ventilator cam allows sampling of expired air only This switch is mounted to the respirator frame such that the valve is open through 90 percent of the expiratory stroke The sample of expired air is delivered from the solenoid valve to the Pco_2 electrode via the inlet tubing Small negative pressure on the outlet tubing facilitates the flow of gas from the animal through the electrode (Fig 3)

OPERATION

The electrode cable is introduced into the glass electrode input of the electrometer (Heath Model EVW-301) For stable operation and to prevent noise artifacts, it is important to ground the recording instrument to a good earth ground The scale expansion and lower pH index functions should be set to provide adequate pen deflections and sensitivity when recording in the normal physiological CO_2 range of 3 to 5%. Temperature of the water bath should be maintained at 37.0°C and the variable temperature switch on the recorder adjusted to this setting A calibration procedure should be performed at the beginning of each new experiment by injecting a series of gas mixtures of known CO_2 concentration and following each injection with introduction of air to allow return to baseline. Capillary Pco_2 may then be estimated according to the formula

$$Pco_2 = P_b - P_{wv} \frac{\%CO_2}{100}$$

where P_b is barometric pressure (mmHg) and P_{wv} is the water-vapor pressure at 37°C (47 mmHg)

In our experimental procedure employing paralyzed artificially ventilated cats, a pH range of 5 and a lower pH index setting of 4 have proven most effective within the 3–5% range. Following calibration, the solenoid valve and vacuum pump are switched on allowing continual monitoring of expired CO_2 concentration Adjustments in rate and depth of respiration can be made to bring the preparation within physiologic limits. During a two year period of operation in our laboratory, this assembly has proven to be an effective and sensitive means of monitoring expired CO_2 levels, detecting changes in this gas within one-half percentage.

SPECIFICATIONS

Response time to injections of calibration gases is within 30 sec. This does not present a significant disadvantage since in operation expired respiratory gas is constantly flowing through the electrode, yielding a continuous on-line recording comparable to commercial units. The total cost of this apparatus is approximately 1/10 ($500 00) that of a purchased instrument.

Lack of a linearizer circuit as incorporated in commercially available gas analyzers limits the linearity of this apparatus over a wide range of gas concentrations. However within the physiological range of 3–5% and with proper instrument settings, linearity is within ± 5%. Use of calibrating gas concentrations of 3, 4 and 5 percent, increases the accuracy and compensates for limits imposed by the nonlinear function This compares favorably to linear operation found in available instruments. With correct maintenance of the electrode which entails changing the electrode membrane and electrolyte solution every 2 to 4 weeks dependent upon use, intraday accuracy and stability are typically within ± 3% This instrument is suitable for measuring CO_2 concentrations which range 3 to 4 percentage points between 0 and 10% Highest accuracies are obtained by limiting the range 3 to 4 percentage points and expanding the scale of the recorder to allow for a greater pen deflection for each percentage point. Admittedly, the narrow range of this instrument would preclude its use in studies dealing specifically with respiratory physiology in which respiratory parameters could deliberately exceed the normal range However, it has proven to be more than adequate in studies in which the primary concern is the acquisition of electrophysiologic data, and only secondarily that this data was obtained under conditions of imposed normal artificial ventilation, i e , end-tidal CO_2 between 3 and 5%

MATERIALS AND MANUFACTURERS

P_{CO_2} electrode (Instrumentation Laboratory, Inc.)
pH Recording Electrometer (Heath Inc , Model EUW-301)
Solenoid valve (Versa Valve)
Transformer (electronic supply house)
Microroller switch (electronic supply house)
Vacuum pump
Respirator (Harvard Apparatus)
Plastic tubing, Tygon tubing, plastic container for water bath (laboratory stock)
Circulating water bath heater (laboratory supplier)
Tank calibrated CO_2 gases (Puritan-Bennett)

ACKNOWLEDGEMENT

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