

Measurement of rates of excretion of sweat solutes under physiological conditions

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BARRUETO, RICHARD B., MILTON MAGER AND DAVID E. BASS. *Measurement of rates of excretion of sweat solutes under physiological conditions.* J. Appl. Physiol. 14(3): 435-438. 1959.—An apparatus is described which permits the study of rates of excretion of sweat solutes under physiological conditions from an arm, and which permits regulation of skin temperature of the arm independent of ambient conditions. The apparatus permits the collection from the arm of all sweat solutes separately from the associated water. This is accomplished by isolating an arm in a thermoregulated copper cylinder. Air is circulated through the cylinder and the sweat water is collected in a trap system; the solutes are subsequently washed from the arm and the washings are analyzed. It was shown that the rates of excretion of sodium, potassium, chloride, 'apparent' creatinine and urea were the same from an arm enclosed in the apparatus as from the unenclosed arm. Thus, the apparatus can be validly used in studying the effects of various environments on sweat gland activity for the five substances measured.

over a skin surface large enough to permit study of rates of excretion of sweat solutes.

Accordingly, we have constructed an apparatus which permits measurement of excretion rates of sweat solutes from an entire arm under physiological conditions, and which permits control of skin temperatures independent of the environment. This report describes the apparatus and presents data validating its use. The apparatus permits the collection from an arm of all sweat solutes separately from the associated water. This is accomplished by isolating an arm in a thermoregulated copper cylinder. Air is circulated through the cylinder and the sweat water is collected in a trap system. The solutes are subsequently washed from the arm and the washings analyzed.

MATERIALS AND METHODS

Description of the apparatus. The apparatus consists of the following major components: a large copper cylinder (arm chamber), trap system, flowmeters, air pump and motor, and a preheater cylinder. Together with these major components, the following auxiliary equipment is used: a thermoregulator, two variac transformers, a voltage indicator, and various lengths of 1/2-inch i.d. glass and tygon tubing. This is schematically shown in figure 1. The entire apparatus is mounted on a wheeled cart for ease of movement (fig. 2).

Arm chamber (fig. 2). The arm chamber is a heavy gauge copper cylinder, 10 inches in diameter and 33 inches long. To seal the unit, it is welded at the seam and at the ends where two flanges are placed perpendicular to the chamber for screws and gaskets connecting various accessories to the chamber. In addition, two flanges 1 inch apart are welded together at the air intake end to act as a baffle. This baffle, packed with glass wool, allows air to diffuse evenly as it enters the chamber. Over this flange is a 1/4-inch thick Lucite pane, which serves as an observation window. The air outlets are at the other end of the chamber, and consist of four evenly

PREVIOUS WORK INDICATES that the most commonly used methods for collecting sweat often do not provide physiologically valid samples (1-3). It was pointed out that these methods may in themselves alter the composition of sweat samples by modifying local skin factors; this is especially so when sweat is collected in vapor impermeable materials, e.g. polyethylene bags and rubber gloves (1, 2).

The assessment of excretion rates of sweat solutes, therefore, becomes unreliable when calculated from analyses of sweat collected under various barriers. McDowell, Lee and Fohrman (4) have described a capsule method for measuring the rate of water evaporation from selected small areas of skin without altering the humidity of the air to which it is exposed. Although this technique is well suited to studying evaporation rates, it does not provide for a wide range of local skin temperatures, independent of the ambient environment,

Received for publication July 31, 1958.

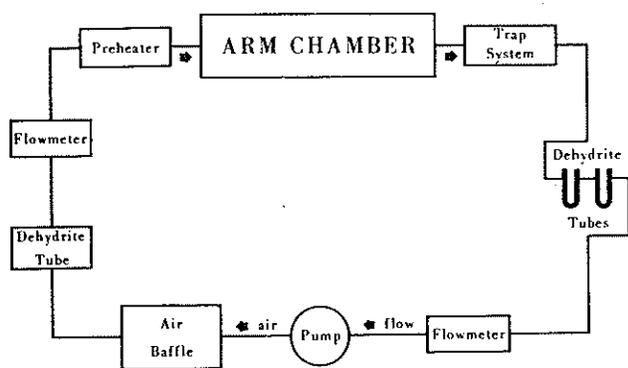


FIG. 1. Flow diagram of apparatus.

spaced tubes ($\frac{1}{2}$ in. in diameter and 1 in. long), welded 1 inch from the edge. Also, at this end is a flange with an orifice 5 inches in diameter, lined with foam rubber, which acts as an arm support. The cylinder is wrapped with a series of heating elements and these in turn are covered with a layer of aluminum foil and two $\frac{1}{4}$ -inch layers of wool cloth. Inside the chamber are two adjustable plastic stirrups which act as arm supports. A small light illuminates the cylinder, while a 6-inch by 24-inch stainless steel pan at the bottom of the chamber collects sweat that may drip from the arm during an experiment.

A thermocouple and a thermistor are installed near the observation window; the electrical leads leave the chamber through one of the outflow openings. The thermocouple is used to determine the air temperature of the chamber, while the thermistor is used to regulate the temperature of the heating elements surrounding the chamber.

Trap system (fig. 2). Water evaporated from the arm during an experiment is collected by a series of traps mounted on top of the arm chamber. The air leaving the chamber first enters a special glass trap in a Dewar flask containing a mixture of absolute ethyl alcohol and liquid nitrogen at -120°C . This mixture is constantly stirred and is kept at this temperature by occasional additions of liquid nitrogen. To insure complete collection of moisture, the air next enters two 'U' tubes filled with magnesium perchlorate (dehydrite). Two glass ball joints allow the removal of the entire trap system from the remainder of the apparatus, while a 3-way glass stopcock makes it possible to bypass the trap system.

Flowmeter (fig. 2). Two Brooks-Mite rotameters, calibrated from 0 to 25 l/min., measure the airflow of the system. One is located next to the pump inlet, the other next to the preheater. A 3-way glass stopcock is attached to each flowmeter assembly, thus providing a bypass after air speed adjustments are completed.

Air pump (fig. 2). Air is circulated through the system by a two-wing No. 26 $\frac{1}{2}$ Lyman Bros. pump. This pump is driven and controlled by a Servospeed motor control system, model 256701 RB, which allows adjustment of the air speed. A closed metal cylinder ($4\frac{1}{2}$ in. in diameter and 21 in. high) filled with calcium chloride serves as

a baffle to eliminate the pulsating character of the air-flow originating in the pump. As a further precaution against impurities, a glass tube filled with dehydrite is situated immediately after the air baffle.

Preheater (fig. 2). The air entering the arm chamber is preheated in a heated copper cylinder, $1\frac{5}{8}$ inches in diameter and 11 inches long. This cylinder is heated by a resistance wire wrapped around the tube, and is covered with a layer of insulation. The preheater was considered necessary to permit finer control of arm temperature and greater uniformity of temperature along the length of the arm.

Heating control (fig. 2). A thermistor electronic thermoregulator maintains a constant temperature in both preheater and arm chamber. The temperatures in these units can be controlled to within 1°F . Two transformers serve to reduce the input to the heating elements. A voltmeter is used to determine the potential applied to either the arm chamber or the preheater heating elements.

Validating experiments. A series of experiments was performed to determine whether the apparatus itself affected sweat solute excretion of an arm. Briefly, the rate of excretion of various solutes was determined for each arm of a subject who was exposed to heat. One arm was enclosed in the apparatus, while the other arm, serving as a control, remained unenclosed. The skin temperature of the enclosed arm was maintained at the same level as that of the control arm by adjusting the

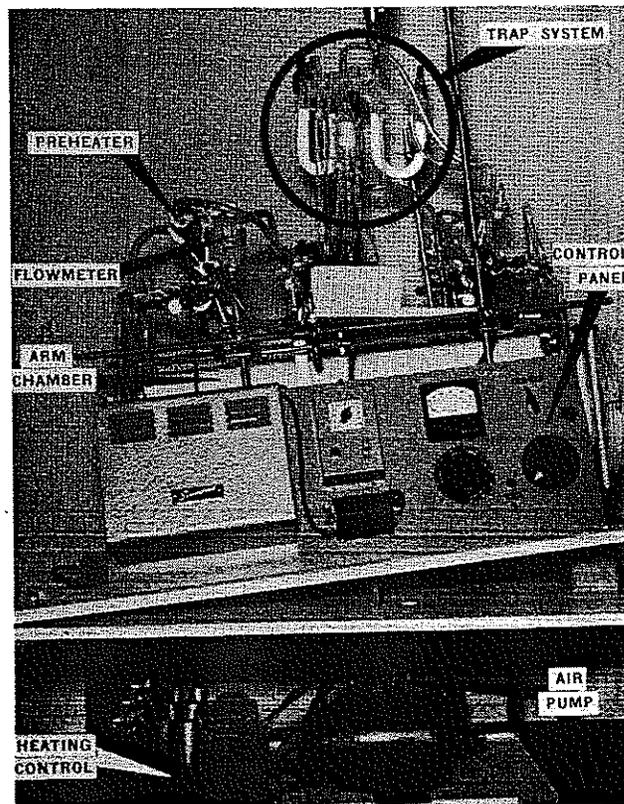


FIG. 2. Assembled apparatus.

heating controls of the arm chamber. The experiments were performed on 16 healthy young volunteers, who were variously exposed to 95°–120°F D.B. and 80°–82°F W.B. for 45–60 minutes in a constant temperature chamber. Before entering the chamber, each test subject showered, then dressed in only shorts and shoes. Following this, his arms were carefully washed with soap and water and thoroughly rinsed with both tap and distilled water. He then was given a surgical swab saturated with ether with which he wiped down the entire arm and hand area.

A copper-constantan thermocouple was placed on the medial dorsal aspect of each arm and forearm for skin temperature measurements. These were secured in place by a thin elastic band and a small amount of Duco cement at the base of the thermocouple. A polyethylene shield (12 in. x 12 in.) was placed on each arm 24 inches from the finger tips and sealed with strips of adhesive tape.

The test subject then entered the constant temperature room, reclined on a wheeled stretcher and inserted one of his arms into the arm chamber. To ensure an airtight seal, a rubber gasket was placed over the polyethylene shield and sealed to the chamber. Dominant arms were enclosed in the chamber in alternate experiments. The other arm was placed on two plastic supports, thus permitting free circulation of ambient air and avoiding contamination. The exposure period was timed commencing with the opening of the valves in the trap system of the arm chamber; normally this occurred within 3 minutes of the time the subject entered the chamber. Skin temperatures were measured continuously with a Leeds & Northrup Co. Speedomax recorder. At the conclusion of the exposure period, the test subject was removed from the constant temperature chamber. The solutes were collected from both arms and analyzed for sodium, potassium, chloride, 'apparent' creatinine and urea. Details of washing and methods of analysis are described in another paper (5).

TABLE 1. Rates of Excretion of Various Sweat Solutes From Enclosed and Exposed Arms

Solute	*No. of Exper.	Condition	Mean Rates $\mu\text{Eq}/\text{min.}$	Result of Sequential Analysis
Sodium	14	Enclosed	15.2	$P = \frac{1}{2}$
		Exposed	15.2	
Potassium	13	Enclosed	3.25	$P = \frac{1}{2}$
		Exposed	3.27	
Chloride	16	Enclosed	13.0	No decision
		Exposed	12.9	
			$\mu\text{g}/\text{min.}$	
'Apparent' creatinine	16	Enclosed	3.05	No decision
		Exposed	2.80	
Urea	12	Enclosed	103	$P = \frac{1}{2}$
		Exposed	101	

* Refers to number of experiments utilized in sequential analyses.

The data were tested for significance by sequential analysis as described by Wald (6); his method was modified by conversion to a two-sided test. The null hypothesis tested was $P = 0.5$ against the alternative $P = 0.8$ or 0.2 . The probability of the Type 1 error was set at $\alpha = 0.1$; probability of the Type 2 error was set at $\beta = 0.05$.

RESULTS

The mean skin temperatures of the exposed and enclosed arms were 99.1° and 99.2°F, respectively, with a mean deviation of 0.5. The results are summarized in table 1.

There was little difference between arms in the mean rate of excretion of all solutes measured. Sequential analysis revealed no significant differences between arms for sodium, potassium and urea. Thus, for these three substances, the general technique described in this paper permits the study of factors affecting the rate of excretion without itself imposing a nonphysiological variable. Although no statistical decision could be reached by sequential analysis for chloride and 'apparent' creatinine, the trend was strongly in favor of reaching a decision that no significant difference existed between arms for these substances. Thus, in the case of chloride, there was an almost equal division of direction of the differences between the control and enclosed arms: 9+ and 7-. For 'apparent' creatinine, the distribution was 6+ and 10-.

DISCUSSION

An important aspect of the environment which is not controlled by this apparatus is humidity. Although the relative humidity in the cylinder was unknown, it was probably not excessively high or low; thus, it was sufficiently low to prevent dripping of liquid sweat, but nevertheless high enough so that the arm was slightly moist at the end of the exposure.

Obviously, the most direct method of measuring excretion rates of sweat solutes is to collect all the sweat from the entire body. This, however, is a long, tedious process and places limitations on the variety of experiments which can be performed. The use of an arm instead of the whole body offers the advantages of ease of collection, the availability of the contralateral arm as a control and ready manipulation of the local environment of the arm. Robinson and Robinson (7) have reviewed methods of collecting sweat for analysis. The method described in this paper provides a means for studying the sweating mechanism in terms of rates of excretion of solutes under conditions which may be considered physiological. Although this technique does not permit the collection of liquid sweat as excreted with its accompanying solutes, it may be possible, nevertheless, to study sweat concentration as well as rates of excretion of various solutes by this method. For example, when we 'reconstituted' the samples from the measured volume

of sweat water and the total solutes collected, the calculated mean concentrations for sodium, potassium and chloride were of the same order of magnitude as those reported for total body sweat (1).

We express our thanks for the cooperation of the test subjects who participated in these experiments, and also to Messrs. Williams T. Farnum, Thaddeus F. Maliszewski and Allan R. MacLeod for their assistance in conducting these experiments, and to Miss A. M. Galligan for her help with the statistical analyses.

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