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SCHOOL OF AVIATION MEDICINE
U.S. NAVAL AIR STATION
PENSACOLA FLORIDA

DETERMINATION OF AQUEOUS VAPOR TENSION IN EXPIRED AIR

Research Project X-475(Av-252-t) Report No. 1

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NAVAL SCHOOL OF AVIATION MEDICINE
U.S. Naval Air Training Bases
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TITLE: DETERMINATION OF AQUEOUS VAPOR TENSION IN EXPIRED AIR

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SUMMARY AND CONCLUSIONS

Many calculations in respiratory physiology involve the assumption that alveolar air has a temperature of 37 degrees C and is completely saturated with water vapor. The determination of the pressures of oxygen and carbon dioxide in the alveolar air, for example, requires correction for water vapor pressure. Furthermore, in relating alveolar gas pressures to the tensions and volumes of gas in the blood leaving the alveolar capillaries, it is customary to refer to dissociation curves established at 37 degrees C. While there is little reason to suspect that alveolar air and pulmonary capillary blood fail to reach general body temperature under normal external environmental conditions, there is a possibility that lung temperatures may be lowered when extremely cold air is breathed. Such lowering of the temperature of alveolar air would, if present, alter the standard correction for water vapor pressure and might even lower the temperature of alveolar blood in capillaries, thus causing a shift in the oxyhemoglobin dissociation curve.

The present study was undertaken to provide direct observations on temperature and humidity of air in the mouth, trachea, and right main bronchus of a human subject. Measurements were taken both when the subject breathed air at room temperature and when he breathed oxygen which was cooled to low temperatures.

APPARATUS

The supplying of extremely cold air to the subject introduced practical difficulties which were avoided by substituting oxygen. In previous testing it had been found that the gas leaving the evaporating chamber of an atmospheric type liquid oxygen converter became progressively colder if the oxygen were allowed to flow at its maximum rate for an extended period of time. In the present studies a Mathier-Milan converter was used as a source of cold oxygen. A standard Navy A-12 diluter demand oxygen regulator was introduced into the system between the liquid oxygen converter and an A-14 mask. For approximately 1/2 hour before each experiment the diaphragm of the regulator was depressed to allow maximal flow. During this time the evaporating chamber and then the regulator and tubing gradually became frosted over. This outer layer of ice served as insulation preventing rapid warming of the oxygen as it flowed from the converter to the mask. The temperature of the gas at the time it was inspired by the subject was measured by means of a thermocouple inside the mask and was found to be -36 degrees C in our experiments.

An instrument was designed wherein two thermocouples were to be placed in a semi-rigid rubber catheter (one thermocouple to be covered with a wet wick) for insertion into the right main bronchus. By placing the thermocouple junctions in the wide, bell-shaped part of the catheter, and inserting that end first, the junctions were kept suspended in air and not allowed to touch surrounding tissues. Air holes were cut in the bell-shaped part of the catheter so that a stream of air could pass over the junctions; in this way the wet and dry temperatures would be those of the air rather than of the trachea.

Constantan and chromel-P were specified as the two metals for the thermocouple construction, since we desired (1) low specific heat of materials so that a low heat capacity would facilitate a rapid response, and (2) a low thermal conductivity so that the temperature at the junction would not be affected by contact of the wire with other materials of different temperatures at points other than the junctions themselves. We also desired very fine wires in the thermocouples in order that the heat capacity would not be raised by the increased mass of metal.

Powell (17) had shown in 1936 that thermocouples could be used for psychrometric purposes, and that the response was much more rapid than for the conventional wet-dry bulb thermometer type of psychrometer. His data show that in unventilated air, the thermocouple psychrometer gives a relative humidity higher than the calculated value by about 2 to 3 percent over most of the range, but at values approaching saturation (R.H.= 97 percent), the reading is only 0.5 percent high. This discrepancy is obviated by ventilation.

The instrument was constructed for us by Professor M. K. Fahnestock of the Engineering Experiment Station of the University of Illinois (Fig. 1). It was due to his suggestion that a switch was incorporated which enabled us to read directly the difference between dry and wet temperatures (ΔT). A cotton broadcloth wick was fashioned to cover the junctions of one of the thermocouples. This was wet with distilled water prior to any measurements, and this wet junction was placed 2 mm proximal to the dry junction by shortening the length of the "wet" thermocouple. This practice was recommended by Powell (17) in order to prevent the freshly vaporized water from affecting the dry reading.

Thirty-four gauge wire was used for both the constantan and chromel-P wire. Thermal potentials were measured by means of a Leeds and Northrup type K-2 potentiometer, using the L&N type R galvanometer as a null-point indicator. This galvanometer has a period of 2.8 seconds and a sensitivity of .0025 µa/mm at a distance of 1 m. With this arrangement, a sensitivity of better than 0.01° C was obtained. Actually, it was found that the physical system was capable of an accuracy much greater than that allowed by the physiological variables.

The introduction into the right main bronchus of the catheter containing the thermocouple was accomplished on both occasions by Lt. Comdr. Joseph K. Bradford (MC) USNR. The subject received 100 mg of nembutal and 1.2 mg of atropine sulfate by mouth approximately 1/2 hour before the procedure was started. Surface anesthesia was obtained with 2 percent larocaine during the first experiment and 5 percent larocaine during the second. The catheter was passed between the vocal cords with the help of indirect laryngoscopy and was then advanced until it was estimated that the tip lay in the right main bronchus.

The anesthesia was not completely satisfactory, and difficulty was encountered in passing the dilated bell-shaped portion of the catheter between the cords. In each case however, the thermocouples were finally placed in the desired position after a few unsuccessful attempts. The thermocouples were left in placo for 15 to 20 minutes on both occasions. Much sticky mucous was present from the start but appeared to increase with time.

RESULTS

After calibration of the thermocouples with regard to temperature and humidity, a test was made to ascertain the rapidity of the response to the changes involved in the different phases. The catheter was placed in a rubber tube that had an inner diameter slightly greater than that of the trumpet end of the catheter. By having a subject expire through this tube in various ways, it was found that the response of the thermocouples was sufficiently rapid.

Table 1 shows that the expired air leaves the throat at about 35° C., and is almost saturated with water vapor at this temperature. Apparently, the first part of the "dead-space" air is less saturated (87%).

Table 2 lists the data obtained from the first experiment in which the catheter containing the wet and dry thermocouples was inserted into the right main bronchus. It can be seen that the inspired air reached body temperature even during hyperventilation of cold, dry oxygen from a Mathis-Milan liquid oxygen generator at -36° C. The consistency of the aqueous vapor tension data appears interesting, but the authors fear that much value cannot be attached to them. The holes in the catheter, provided for free air passage, became plugged with mucus, and the wet temperature as well as the dry temperature readings remained constant during the different phases of respiration. One possible explanation of the unsaturation under these conditions is that the humidity readings were a measurement of the air in the trumpet-shaped end of the catheter, which in turn would probably reflect the aqueous vapor pressure of the mucus plugging the holes in the catheter wall.

It will be noted that the lung air temperature was about a degree higher than "normal" body temperature. It is believed that the subject's body temperature was raised by the coughing during the introduction of the catheter.

Table 3 presents the data obtained during a second experiment with the thermocouples in the right main bronchus. A higher concentration of the anaesthetic was used, and also the temperature of the inspired air was measured at different levels in the trachea while the subject breathed dry oxygen at -21° to -25° C. In this series, it will be noted that the lung air temperature did not deviate significantly from the "normal" body temperature of 37° C.

The comments made concerning the unreliability of the water-vapor data of the first tracheal experiment may be repeated in a discussion of the second. Here again there was no deviation of wet or dry temperatures after the catheter had reached the right main bronchus, and again it was noted that the holes cut in the catheter wall were filled with mucus.

DISCUSSION

The experimental results with the thermocouples in the mouth should not have been affected by the poor ventilation which influenced the results with the thermocouples in the right bronchus. It was noted that the expired air was almost completely saturated with water vapor, and these results are in close agreement with those of Liljestrand and Sahlstedt (10) who weighed the expired water vapor absorbed by desiccants.

The aqueous saturation observed in all three of our experiments indicates that the water vapor content of expired air is independent of the rate of respiration, a fact already noted by Spealman (15) in connection with his calculations of heat loss through the lungs as a result of water evaporation.

While the vapor pressures in the right main bronchus are admittedly open to question for reasons already given, the temperature data appear to be reliable. The fact that we found cold (-36° C) dry oxygen warmed to body temperature, even during hyperventilation is quite in keeping with the results of Moritz and Weisiger (11) who made thermocouple measurements of the tracheal air of anaesthetized dogs while the animals were breathing air at temperatures as low as -100° C for periods of time ranging from 20 to 133 minutes. While the inspiratory temperatures at the larynx in their experiments were sometimes as low as -50° C, they were never lower than $+18^{\circ}$ C at the bifurcation of the trachea. These authors concluded that it is unlikely that any significant injury to the air passages or lungs in man would result from breathing air at any degree of coldness encountered in non-experimental conditions. The results of the present experiments substantiates ~~this view.~~

At the Banting Institute an experiment similar to that done by Moritz and Weisiger was performed, except that thermocouple temperature measurements were made of the tracheal wall. Inspired air colled to -62° had no effect on the tracheal temperatures of anaesthetized dogs.

In 1927 Binger and Christie (4) and Orzagh and Duboczky (12) inserted thermocouple containing needles directly into the lungs of anaesthetized dogs during normal breathing at room temperatures and found the lung and pleural tissues to be slightly lower than rectal temperatures. The former authors obtained a difference of 0.3 to 0.4° C while the latter noted 0.1 to 0.2° C.

The various experiments which have been performed lead to the conclusion that breathing cold air does not lower the temperature of alveolar air appreciably except under conditions much more vigorous than those of the experiments reported here. Since the chilling effect of air becomes less at high altitude, there is little possibility that effects upon the alveoli of physiological significance will be encountered in aviation medicine.

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TABLE 1

Temperature and Relative Humidity of Expired Air.
Subject Expiring Through Rubber Tube
While Breathing Air at 25.9° C.

A. Breathing through nose. Only last part of expiration ("alveolar air") passing through tube. Thermocouples near front teeth.

Dry Temp. °C	Δ Temp. °C	Wet Temp. °C	pH_2O Exp. mm. Hg	Relative Humidity Percent
34.95	0.10	34.85	41.82	99.4

B. Same as A, except first part of expiration passing through tube.

Dry Temp. °C	Δ Temp. °C	Wet Temp. °C	pH_2O Exp. mm. Hg.	Relative Humidity Percent
34.88	2.42	32.46	36.47	87.1

C. Same as A, except thermocouples near pharynx.

Dry Temp. °C	Δ Temp. °C	Wet Temp. °C	pH_2O Exp. mm. Hg.	Relative Humidity Percent
35.50	0.47	35.03	42.17	97.5

TABLE 2

Temperature and Relative Humidity Measurements in Right Main Bronchus. First Experiment.

Breathing Type	Breathing Route	Inspired Air Temp. °C	Dry Temp. °C	Δ Temp. °C	Wet Temp. °C	pH_2O mm.Hg	R.H. %
Normal	Nose	-24.2	37.82	1.08	36.74	46.39	94.1
Hyperven.	Mouth	-24.2	37.96	1.06	36.90	46.75	94.1
Hyperven.	Nose	-36.5	37.92	0.98	36.94	46.87	94.9
Normal	Mouth	-36.5	37.81	1.09	36.72	46.33	94.1
Normal	Nose	+22.4	37.95	1.09	36.86	46.67	[illegible]
Hyperven.	Mouth	+22.4	38.10	1.37	36.73	46.34	93.0
Hyperven.	Nose	+22.4	37.75	1.26	36.49	45.75	93.2
Normal	Mouth	+22.4	37.70	1.26	36.44	45.62	93.5

1/2 hour after experiment:

Mouth Temp. = 36.5° C

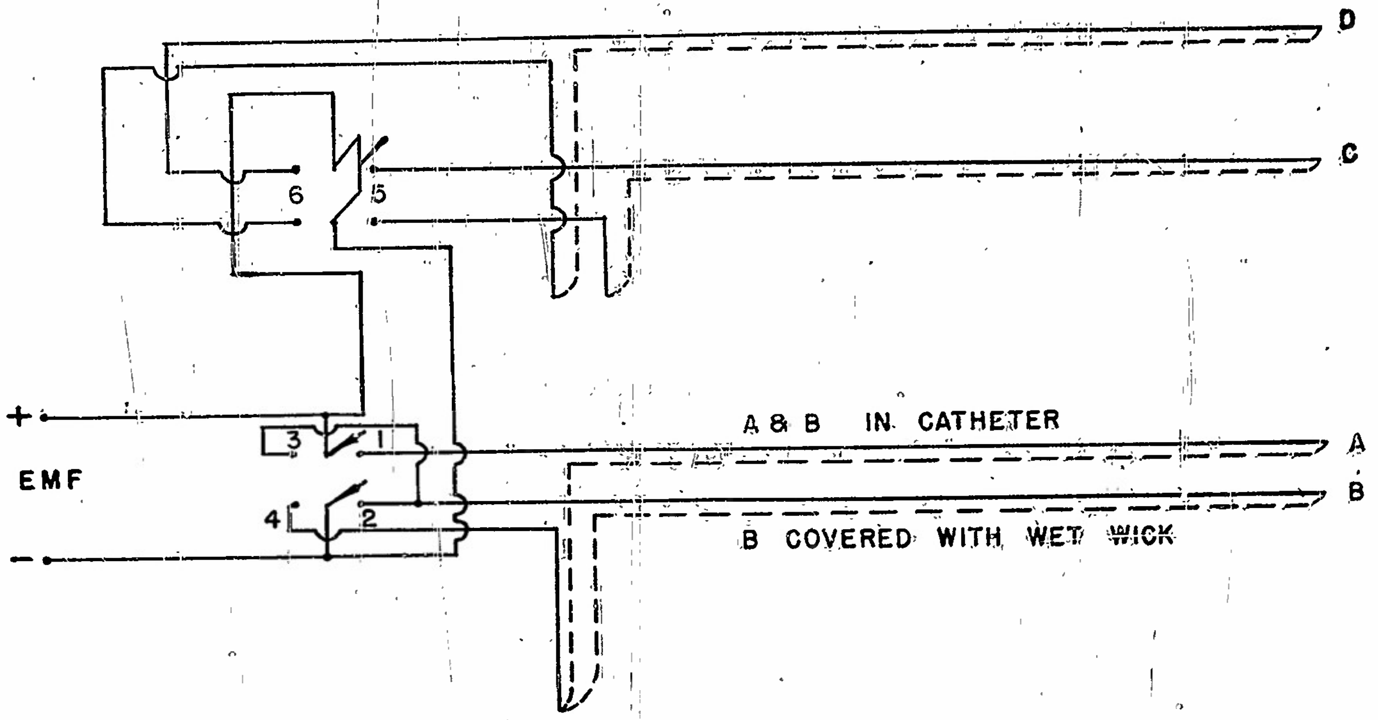
Rectal Temp. = 36.8° C

TABLE 3

Temperature and Relative Humidity Measurements in Trachea and Right Main Bronchus. Second Experiment.

Location of Thermocouples	Breathing			Inspired Air Temp. °C	Dry Temp. °C	Δ Temp. °C	Wet Temp. °C	pH$_2$O mm. Hg	R.H. %
	Phase	Type	Route						
Glottis	Insp.	Hyper.	Mouth	-21.0	36.80	-	-	-	-
4" Below Glottis	Insp.	Hyper.	Mouth	-24.2	37.05	-	-	-	-
Rt. Main Bronchus	Insp.	Hyper.	Mouth	-24.2	37.03	0.60	36.	45.63	96.6
Rt. Main Bronchus	Exp.	Hyper.	Mouth	-25.0	36.95	0.64	36.31	45.33	96.6
	Insp. and Exp.	Hyper.	Mouth	+23.2	37.04	0.73	36.31	45.31	96.0
		Normal	Nose	+23.2	37.25	0.77	36.48	45.76	95.8
		Normal	Nose	-21.5	37.12	0.78	36.34	45.38	95.8

Mouth Temp. = 36.9° C



TO READ A,	CLOSE 1 & 4
B	3 & 4
A-B	1 & 2
C	5
D	6

FIGURE I. DIAGRAM OF THERMOCOUPLE SYSTEM

—— CONSTANTAN

– – – – CHROMEL-P