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**Contributors**

Boothby, Walter M.  
Sandiford, Irene

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AND THE CONNELL ANAESTHETOMETER

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W. M. BOOTHBY AND I. SANDIFORD

*From the Surgical Service and Respiration Laboratory of the Peter Bent Brigham  
Hospital, Boston. Clinic of Professor Cushing*

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## THE CALIBRATION OF THE WALLER GAS BALANCE AND THE CONNELL ANAESTHETOMETER

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For the determination of the anaesthetic tension of ether vapor in man, the Connell anaesthetometer<sup>1</sup> was used. The accuracy of this apparatus was determined by means of the Waller gas balance. In using this balance care must be exercised in determining the effective ascensional volume of the glass bulb, in working out the weight of the rider, and in making the necessary corrections for barometer, temperature, vapor tension of water, and the alcohol content of ether. This involves considerable mathematical calculation and we have therefore given our method of calibration in detail.

The Waller gas balance consists of a glass bulb of known volume, counterpoised by a brass weight, also of known volume. As mixtures of ether and air of varying densities are passed into the balance-case, the glass bulb rises or falls with the increase or decrease in the density of the mixture.

The composition of the ether-air mixture can be expressed in per cent by volume or per cent by weight. Care must be exercised not to confuse the two forms of expression. In the case of the Waller gas balance, the per cent by volume is used since the volume of ether for various percentages and the corresponding litre weight difference progress according to a straight linear ratio. This is not true of percentages by weight, as is shown by table 1, in which are given the litre weight differences between

<sup>1</sup> Connell: An Apparatus—Anaesthetometer—for Measuring and Mixing Anaesthetic and Other Vapors and Gases. Surg., Gyn. and Obstet., xvii, no. 2, 245-255, 1913.



varying percentages (a) by volume, and (b) by weight of ether and air at 760 mm. and 0°, dry. Furthermore, percentage by volume is preferable to percentage by weight because it is readily convertible into tension.

TABLE 1

PER CENT	LITRE WEIGHT DIFFERENCE FOR	
	(a) Percentage by volume	(b) Percentage by weight
	<i>grams</i>	<i>grams</i>
20	0.4031	0.1794
40	0.8062	0.4167
60	1.2093	0.7447
80	1.6124	1.2289
100	2.0155	2.0155

Therefore a rider of proper weight for the effective ascensional volume, when moved along the balance beam, will represent proportional changes in the volume per cent of ether. The following calculations are necessary to obtain the value of such a rider:<sup>2</sup>

<sup>2</sup> The value of the counterpoise corresponding to a certain per cent *by weight* is found by the following calculations:

P = 760; T = 0°; Per cent by weight = 20

*Grams*

Weight 1 litre ether at 760 mm. and 0° = 3.3086

Weight 1 litre dry air at 760 mm. and 0° = 1.2932

20 grams ether = 6.044 L.

80 grams air = 61.863 L.

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100 grams mixture = 67.907 L.

*Grams*

1 litre of above mixture = 1.4726

1 litre of dry air = 1.2932

Weight counterpoise for 20 per cent by weight = 0.1794

To change percentage by weight to percentage by volume, using above data:

20 per cent by weight of ether = 6.044 L.

Total volume ether-air mixture = 67.907 L.

20 per cent by weight =  $\frac{6.044}{67.907}$  = 8.90 per cent by volume.



	<i>cc.</i>
(1) Volume of glass bulb (from water displacement)	= 839
Volume of brass counterpoise (from water displacement)	= 14
Effective ascensional volume	= 825
	<i>grams</i>
(2) Weight 1 litre pure ether vapor at 760 mm. and 0°	= 3.3086
Weight 1 litre dry air at 760 mm. and 0°	= 1.2932
Litre weight difference of mixture	= 2.0154
(3) $2.0154 \times \frac{825}{1000} = 1.6629$ grams.	
(4) $\frac{1.6629}{4} = .4157$ grams = 415.7 milligrams = weight of 25 per cent rider.	

The accuracy of the individual determination is increased by the use of a 25 per cent rider instead of a 100 per cent rider.

To allow for changes in barometer, temperature, vapor tension of water, and alcohol content of ether, the percentage reading must be corrected by the formula:

$$P = p \left[ \frac{w}{(W - A) \frac{V}{1000}} \right]$$

Where  $P$  = corrected per cent,

$p$  = observed per cent,

$w$  = weight standard rider for the effective ascensional volume, at 760 mm. and 0° dry,

$W$  = weight rider, correct for the experimental temperature, and pressure for 1000 cc. (Table 2),

$A$  = weight to be subtracted for alcohol content (Table 3),

$V$  = effective ascensional volume.

The weights of riders correct for the ordinary changes in temperature, and pressure, have been worked out as above for a 1000 cc. effective ascensional volume and are presently given in tabular form.

To allow for the alcohol content ( $A$ ) of ether prepared for anaesthetic purposes, the rider must be modified in order to determine the additive per cent of the vapor of ethyl ether and



ethyl alcohol. For example, Squibb's or Parke, Davis and Company's ether contains 3 per cent by weight of alcohol, and the calculation of the rider for 760 mm. and 20° is as follows:

Weight 1 litre ether vapor at 760 mm. and 20° = 3.0831 grams.

Weight 1 litre alcohol at 760 mm. and 20° = 1.9164 grams.

Then 97 grams ether = 31.463 L.

3 grams alcohol = 1.565 L.

---

100 grams mixture = 33.028 L.

3.0277 grams mixture = 1.0 L.

Therefore 1 litre of anaesthetic ether vapor containing 3 per cent by weight of alcohol, weighs 3.0277 grams. The difference (0.0554 gram) between the pure and the impure ether vapor must be subtracted from the litre weight difference of the ether-air mixture, or if this weight is divided by 4 (0.014 gram) it can be subtracted from the weight of the corresponding 25 per cent rider. The amount of correction for 2 per cent, 3 per cent and 4 per cent by weight of alcohol in ether is given below. Barometer and temperature changes affect this correction factor very little and they are therefore negligible. This correction should be used only when the ether and alcohol are completely volatilized, as in the case of the Connell meter. When the air current passes over liquid ether, containing alcohol, this correction is unnecessary, since the low vapor tension of alcohol will prevent its being volatilized to any extent.

TABLE 2

*25 per cent ether riders for 1000 cc. bulb*

	<i>P</i> <i>Corr. Bar.</i>	<i>T</i>		
		18°	20°	22°
	<i>mm.</i>	<i>mgm.</i>	<i>mgm.</i>	<i>mgm.</i>
1. Dry air.....	755	469.7	466.5	463.3
	760	472.9	469.6	466.4
	765	475.9	472.7	469.5
2. Saturated air.....	755	471.9	469.0	466.1
	760	475.1	472.1	469.2
	765	478.1	475.2	472.3
3. Air 40 per cent saturated.....	755	470.5	467.4	464.4
	760	473.7	470.6	467.5
	765	476.7	473.6	470.5



TABLE 3  
*Alcohol corrections*

ALCOHOL BY WEIGHT	CORRECTION*
<i>per cent</i>	<i>mgm.</i>
2	9.5
3	14.0
4	18.6

\* To be subtracted from weight of riders given in table 2.

The following example illustrates the use of the formula and tables just given to correct the observed per cent for temperature, barometer, vapor tension of water and alcohol content of ether.

Barometer = 764.4;<sup>3</sup> Temperature = 21°.

Effective ascensional volume of bulb = 825 cc.

Weight of standard rider for 825 cc. at 760 mm. and 0° = 415.7 mgm.

Percentage saturation of air with water vapor = 40 per cent.

Alcohol content of ether = 3 per cent by weight.

Observed per cent = 5.58 per cent.

Substituting in the formula

$$P = p \left[ \frac{w}{(W - A) \frac{V}{1000}} \right]$$

$$P = 5.58 \left[ \frac{415.7}{(471.4 - 14.0) \frac{825}{1000}} \right] = 5.58 \left( \frac{415.7}{377.4} \right) = 6.15 \text{ per cent}$$

6.15 per cent by volume  $\times$  764.4 = 47.0 mm. the additive tension of ether and alcohol.

The vapor tension of water has been allowed for in correcting the percentage reading and therefore need not be subtracted from the barometer reading.

In one article<sup>4</sup> by Dr. Waller as to the use of the balance for giving ether percentages when primarily calibrated for chloroform, he states that a scale representing 1, 2, 3 per cent for

<sup>3</sup> All barometer readings corrected to 0°.

<sup>4</sup> Journ. Physiol., xxxvii.



chloroform is equivalent to an ether scale of 2, 4, 6 per cent. This statement refers to percentages by volume for both ether and chloroform and is correct. In a later paper<sup>5</sup> he states that a scale representing 1, 2, 3 per cent for chloroform is equivalent to an ether scale of 5, 10, and 15 per cent. The following table shows, however, that no such relationship exists for a percentage by volume, and that it only approximates a percentage by weight.

TABLE 4

	<i>mm.</i>	<i>mgm.</i>
A 5 per cent by volume chloroform rider at 760 and 0°, dry =		201.9
A 10 per cent by volume ether rider at 760 and 0°, dry =		201.5
A 25 per cent by volume ether rider at 760 and 0°, dry =		503.9
A 25 per cent by weight ether rider at 760 and 0°, dry =		232.0

For accuracy in determining ether percentages, a good balance and an air-tight balance case are needed. The zero of the balance must be accurately determined several times during an experiment, because the balance is constructed for the purpose of emphasizing changes in density, and therefore slight variations in pressure and temperature affect the zero point materially. The rider<sup>6</sup> should be adjusted to give an approximate equilibrium during the passage of the ether-air current. The current should then be interrupted and the exact zero quickly determined by the three point oscillatory method. The sensitiveness of the balance having been independently determined, and the displacement of the pointer for 1 per cent ether known, the percentage of ether vapor can be readily determined with great accuracy. The sensitiveness of our balance renders the percentage reading accurate to within  $\pm 0.03$ .

The Connell meter is constructed so as to deliver a definite volume (and weight) of liquid ether with a definite volume of air, giving a mixture of definite percentage by weight of ether vapor in air. The accuracy of the meter was found by determining the error both of the dry meter and of the piston displacement of liquid ether, and finally by testing the delivered mixture by means of the Waller gas balance.

The two usual methods for determining the accuracy of meters, that is, the use of a known volume of air or of a known

<sup>5</sup> Third Interim Report of the British Committee on Anaesthesia, p. 11.



weight of oxygen, were used to find the error of the meter. Seven such determinations at various speeds gave the average correction as +6.5 per cent, that is, the volume recorded on the meter was less by 6.5 per cent than the volume actually passed through.

The amount of liquid ether displaced by the piston was found to be within 0.1 per cent of the theoretical amount, so that the error here for practical purposes was negligible.

Finally, the percentage composition of the ether and air as delivered by the anaesthetometer was tested by means of the Waller gas balance. The Connell is calibrated according to percentage by weight; the Waller according to percentage by volume. In the following paper by Boothby<sup>6</sup> the proportion of ether present has been expressed in millimeter Hg., representing the partial pressure or tension of ether; therefore for comparison, all the determinations in this paper have been reduced to tension. The accuracy of the Connell for the various available tensions is shown in the following table:

TABLE 5

1 NO. TEETH	2 TENSION ON CONNELL	3 CORRECTED TENSION*	4 TENSION ON WALLER*	5 CORRECTION
	mm.	mm.	mm.	mm.
4	25.5	25.2	23.8	-1.4
7	43.5	43.1	41.9	-1.2
8	49.3	48.9	46.2	-2.7
9	55.0	54.3	53.1	-1.2
11	66.1	65.6	62.4	-3.2
12	71.6	71.1	69.6	-1.5
14	82.2	81.6	79.3	-2.3
16	92.6	91.8	88.5	-3.3
Average correction.....				-2.1

\* Additive tension of the vapors of ether and alcohol. The determinations of column 4 are the average of several readings which may vary  $\pm 1$  mm., showing that the ether delivery of the Connell fluctuates slightly.

The average vapor tension of water is taken as 40 per cent. The alcohol content of ether used is 3 per cent by weight and the specific gravity 0.716.

<sup>6</sup> Boothby: Determination of the Anaesthetic Tension of Ether Vapor in Man.



The values in column 2 are calculated according to the formula used by Dr. Connell in which he assumes the meter accurate at a pressure of 30 mm. in excess of the normal barometric pressure (760 mm.), at a temperature of 22° and with saturated air. The formula is

$$Pw = \frac{ET}{ET + 4A}$$

where  $Pw$  = percentage by weight of ether,

$E$  = weight of ether per tooth = 0.1104 gram,

$T$  = number of teeth,

$A$  = weight of 1 litre saturated air at 790 mm. (760 + 30) and 22° = 1.2314 grams.

Substituting in this formula,

$$\frac{0.1104 \times 4}{(0.1104 \times 4) + (1.2314 \times 4)} = \frac{0.4416}{5.3672} = 8.23 \text{ per cent by weight.}$$

8.23 per cent by weight = 3.35 per cent by volume = 25.5 mm.

In the corrected calculations of the percentage delivery of the anaesthetometer given in column, 3, we have used the actual error of the meter, instead of assuming that it is correct for 30 mm., as thereby the slight errors of temperature, pressure, vapor tension of water, alcohol content of ether can be allowed for.

The formula used by us is

$$P'w = \frac{E'DT}{E'DT + A'(4 + 4M)}$$

where  $P'w$  = corrected percentage by weight of ether,

$E'$  = volume of liquid ether per tooth,

$D$  = specific gravity of ether,

$T$  = number of teeth,

$A'$  = weight of 1 litre air at observed temperature and pressure,

$M$  = percentage error of meter, determined by experiment.

Substituting in this formula,

when  $E' = 0.1542$  cc.



$$D = 0.716$$

$$T = 4$$

$$A' = 1.2282 \text{ grams weight of air at 780 mm. and } 21^{\circ}, \text{ air} \\ 40 \text{ per cent saturated with water vapor,}$$

$$M = 6.5 \text{ per cent.}$$

$$\frac{0.1542 \times 0.716 \times 4}{0.4416 + 1.2282 [4 + (4 \times 0.065)]} = \frac{0.4416}{5.6737} = 7.78 \text{ per cent by} \\ \text{weight of ether and alcohol.}$$

To change percentages by weight to percentages by volume, allowing for the alcohol content of ether, the following procedure is necessary:

Alcohol content of ether = 3% by weight

$$7.78\% \times 0.03 = 0.23 \text{ per cent alcohol by weight}$$

$$7.78\% \times 0.97 = 7.55 \text{ per cent ether by weight}$$

$$1 \text{ L ether at 780 mm. and } 21^{\circ} = 3.1531 \text{ grams}$$

$$1 \text{ L alcohol at 780 mm. and } 21^{\circ} = 1.9601 \text{ grams}$$

$$1 \text{ L air, 40\% saturated at 780 mm. and } 21^{\circ} = 1.2282 \text{ grams}$$

$$0.23 \text{ grams alcohol} = 0.117 \text{ L} = 0.15\% \text{ by vol.} = 1.17 \text{ mm. tension of alcohol}$$

$$7.55 \text{ grams ether} = 2.394 \text{ L} = 3.09\% \text{ by vol.} = 24.1 \text{ mm. tension of ether}$$

$$92.22 \text{ grams air} = 75.085 \text{ L} \quad 3.24\% \text{ by vol.} = 25.3 \text{ mm. tension of alcohol}$$

$$100.00 \text{ grams mixture} = 77.596 \text{ L} \quad \text{and ether}$$

In order to get such close agreement between the calculated tension and the true tension, it was necessary to slightly modify the Connell meter by introducing a Müller water valve in the air vent between the vaporizer and the ether container. If this pipe is freely open, ether diffuses back through it, thereby increasing the delivered mixture by 5 to 10 mm., depending on the amount of heat that is conducted to the ether container from the electric heater under the vaporizer.

From the table, it is seen that ordinary barometric and temperature variations affect the tension very little. The following calculation shows that the vapor tension of ether as delivered by the apparatus likewise adjusts itself to barometric changes due to an elevation above sea-level:



when  $E' = 0.1542$  cc.

$D = 0.716$

$T = 4$

$A' = 0.9911$  gram the weight of air at 630 mm. and  $21^\circ$ ,  
and 40 per cent saturated.

then

$$\frac{0.1542 \times 0.716 \times 4}{0.4416 + 0.9911 [4 + (4 \times 0.065)]} = \frac{0.4416}{4.6637} = 9.47 \text{ per cent by weight.}$$

	BAROMETER	PER CENT BY WEIGHT	PER CENT BY VOLUME	TENSION
	mm.			mm.
Colorado Springs (6000 feet) ..	630	9.47	3.98	25.1
Sea-level .....	780	7.78	3.24	25.3

The trip-valves of the additional fourth unit put on by Dr. Connell for mixing true gases, are not sufficiently accurate to justify their use.

#### SUMMARY

1. The calculations necessary for calibrating the Waller gas balance for ether are given in detail. Tables are appended to simplify the corrections needed for variations in barometer, temperature, water vapor, and alcohol content of ether. It is probable that the corrected tension is accurate to within  $\pm 0.2$  mm.

2. By means of the Waller gas balance, thus calibrated, the Connell anaesthetometer has been tested and it was found that the tension of ether delivered by our apparatus was on the average 2.1 mm. too high, the maximum error being  $+3.3$  mm. The Connell apparatus adjusts itself to atmospheric conditions if the ether delivery is expressed in tension and not in percentages.





