Current Comment

STUART C. CULLEN, Editor

Calibration of Wright Spirometer

Kenneth D. Hall, M.D., and Frederick H. Reeser, Jr., A.B.

In recent years, interest has mounted in the measurement of pulmonary ventilation.
Various respiratory monitors are used today as clinical, teaching, and investigational aids, but
many have limitations.

To be an effective respiratory monitor, an
instrument should have, at least, the following
requisites: (1) accuracy and precision, (2)
low resistance and inertia, (3) a compact size,
(4) easy readability, (5) unidirectional re-
cording, (6) ease of connection to the patient
or animal, and (7) reasonable cost.

These qualifications will be discussed under
results as they apply to the Wright respirom-
eter. Dr. B. M. Wright developed this instru-
ment, first mentioned in 1955 and described
in detail in 1959. It possesses many of the
above requisites that are lacking in other
similar instruments.

Although a few data on its performance are
available from England, a more comprehen-
sive calibration of two of these instruments
available here might be of interest.

Method. Two Wright respirometers were
purchased and immediately calibrated. The
serial numbers of 1365 and 2348 would imply
that they were about 1000 apart, production-
wise, and might be expected to represent a
fair sampling of a mass produced instrument.

STATIC CALIBRATION: Each meter was
connected in series with a rotameter (Fischer
and Porter, ±1 per cent accuracy) and a
vacuum source. Vacuum was used to avoid
contamination of either gauge. Temperature,
barometric pressure, pressure drop across the
meters, and position of the meters were meas-
ured and were found to have a negligible
effect within the limits of the experiment.
Therefore, these figures are omitted.

The authors are in the Division of Anesthesia,
Duke University Medical Center, Durham, North
Carolina.

DYNAMIC CALIBRATION: Each meter was
connected to the inspiration side of a sinus-
oidal pump (Palmer), again to avoid contami-
nation of the meter from grease, etc., from the
pump, and also to avoid turbulence arising in
the pump at the higher speeds. The intake
side of the Wright meter was left open to
atmospheric air. Again, various parameters,
such as temperature, were measured, but the
data are omitted since they do not contribute
to the results. Each meter was tested at differ-
tent tidal airs and different rates of the
pump. The sinusoidal pump was statically
calibrated with rotameters, standard gas
meters, and water displacement. Pressure
drop across the Wright meter at different rates
and tidal airs were recorded with a Statham
transducer and Grass Polygraph. The trans-
ducer, in turn was calibrated with a diagonal
water manometer accurate to ±1 mm. of
water.

Results and Comments. Table 1 and figure
1 show the results of the static calibration.
There is a threshold below which the meters
stick and record no flow; this was 3.8 liters/
minute with one meter and 1.5 liters/minute
with the other. This is probably due to bear-
ing friction, not inertia, as the same results
are obtained by either increasing or decreasing
the air flow through the meter. As seen in
figure 1, there is a large negative error at low
flows, probably due to slippage of air past
the vanes. This decreases until flows of about
18 liters/minute, at which point the meter
becomes very accurate. At greater flows a
positive error occurs and reaches its maximum
at about 30 liters/minute, but never exceeds
10 per cent. This might be due to turbulence
at the higher flows, but there is no evidence
for this. These results are in close agreement
with the work of Byles.

Table 2 and figure 2 show the results of
the dynamic calibration. There is a consider-
able negative error at the very low tidal airs and low rates probably due to the air slippage and bearing friction mentioned above. At the higher flows and rates, however, a large positive error appears. This has not been reported before to our knowledge. Upon observing the meter, it is apparent that this positive error is due to "coasting" or inertia of the vanes, within limits, as the positive error is greater as the rate and/or tidal air increases. The product of these two factors determines the maximum inhalation velocity. Indeed, at the

TABLE 1. Static Calibration of Wright Respirometers Air Flow (Cournant) in Liters Per Minute

<table>
<thead>
<tr>
<th>Standard</th>
<th>Wright No. 1365</th>
<th>Error (%)</th>
<th>Wright No. 2348</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>2.1</td>
<td>-1.4</td>
<td>.8</td>
<td>-45</td>
</tr>
<tr>
<td>1.9</td>
<td>2.8</td>
<td>-1.2</td>
<td>2.4</td>
<td>-37</td>
</tr>
<tr>
<td>2.4</td>
<td>3.3</td>
<td>-1.1</td>
<td>3.8</td>
<td>-23</td>
</tr>
<tr>
<td>3.8</td>
<td>4.4</td>
<td>-1.0</td>
<td>4.8</td>
<td>-19</td>
</tr>
<tr>
<td>4.3</td>
<td>5.9</td>
<td>-1.0</td>
<td>5.9</td>
<td>-4</td>
</tr>
<tr>
<td>4.8</td>
<td>6.4</td>
<td>-1.0</td>
<td>6.4</td>
<td>-3</td>
</tr>
<tr>
<td>5.9</td>
<td>7.0</td>
<td>-1.0</td>
<td>7.0</td>
<td>-9</td>
</tr>
<tr>
<td>6.1</td>
<td>7.4</td>
<td>-1.0</td>
<td>7.4</td>
<td>-4</td>
</tr>
<tr>
<td>6.4</td>
<td>8.1</td>
<td>-1.0</td>
<td>8.1</td>
<td>-6</td>
</tr>
<tr>
<td>7.0</td>
<td>8.4</td>
<td>-1.0</td>
<td>8.4</td>
<td>-4</td>
</tr>
<tr>
<td>8.8</td>
<td>9.1</td>
<td>-1.0</td>
<td>9.1</td>
<td>-6</td>
</tr>
<tr>
<td>9.1</td>
<td>11.3</td>
<td>-1.0</td>
<td>11.3</td>
<td>-2</td>
</tr>
<tr>
<td>11.8</td>
<td>17.8</td>
<td>+1</td>
<td>18.5</td>
<td>+4</td>
</tr>
<tr>
<td>20.7</td>
<td>21.0</td>
<td>+1</td>
<td>21.0</td>
<td>-3</td>
</tr>
<tr>
<td>21.8</td>
<td>31.9</td>
<td>+7</td>
<td>32.5</td>
<td>+8</td>
</tr>
<tr>
<td>30.0</td>
<td>37.4</td>
<td>+4</td>
<td>37.8</td>
<td>+5</td>
</tr>
</tbody>
</table>

Standard = rotometer. Wright Nos. 1365 and 2348 = 2 different respiratory meters. Percentage error = deviation from standard. Negative error indicates Wright meter reads lower than standard (Fig. 1).

very fast respiratory rates, the next breath ensues before the meter stops coasting from the previous breath. This, of course, reduces the positive error and is self-correcting by limiting the coasting time. This latter effect occurs only at rates well above 40 breaths per minute and therefore has little clinical interest.

At a given rate the two meters are very close to each other, although far from the theoretical. The precision is good, but the

TABLE 2. Dynamic Calibration of Wright Meters—Intermittent Air Flow—Sinusoidal Tidal Air in Cubic Centimeters, Uncorrected

<table>
<thead>
<tr>
<th>Standard</th>
<th>Respiratory Rate: 10</th>
<th>Respiratory Rate: 25</th>
<th>Respiratory Rate: 40</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. 1365</td>
<td>No. 2348</td>
<td>No. 1365</td>
</tr>
<tr>
<td>48</td>
<td>32</td>
<td>35</td>
<td>43</td>
</tr>
<tr>
<td>93</td>
<td>89</td>
<td>92</td>
<td>101</td>
</tr>
<tr>
<td>138</td>
<td>144</td>
<td>148</td>
<td>161</td>
</tr>
<tr>
<td>183</td>
<td>234</td>
<td>234</td>
<td>219</td>
</tr>
<tr>
<td>228</td>
<td>258</td>
<td>269</td>
<td>277</td>
</tr>
<tr>
<td>272</td>
<td>316</td>
<td>318</td>
<td>332</td>
</tr>
<tr>
<td>318</td>
<td>378</td>
<td>372</td>
<td>407</td>
</tr>
<tr>
<td>363</td>
<td>445</td>
<td>430</td>
<td>447</td>
</tr>
<tr>
<td>408</td>
<td>477</td>
<td>487</td>
<td>492</td>
</tr>
<tr>
<td>451</td>
<td>532</td>
<td>554</td>
<td>541</td>
</tr>
</tbody>
</table>

Standard = Palmer pump. Respiratory rate in strokes of pump per minute. All figures are cubic centimeters of air per stroke (see fig. 2).
accuracy is not nearly as good. It occurred to us, therefore, that a simple correction factor might be found that would be applicable to all meters of this design. Plotting the percentage error versus the respiratory rate (not shown) revealed a straight line from which the following formula was derived:

\[ V_e = V_m - K_1(R - K_2)V_m \]

where:
- \( V_e \) = Volume (tidal air) in cc., corrected.
- \( V_m \) = Volume (tidal air) in cc., measured by Wright meter.
- \( R \) = Respiratory rate.
- \( K_1 = \frac{\text{positive error per breath}}{100} \) (caused by coasting) inherent in design of meter.
- \( K_2 \) = Threshold below which the respiratory rate is so slow that coasting is negligible.

For example: if \( K_2 = 8 \), then at a respiratory rate of 8 the second factor on the right hand side of the equation = 0, and \( V_e = V_m \); that is, no correction is necessary. Below this rate the formula is not applicable. \( K_1 \) apparently varies slightly with each meter. This formula may well be applied to all meters since the two random samples tested here are corrected well by it, with one exception: the threshold constant, \( K_2 \), varies with the two meters, being 8 for no. 1365, and 5 for no. 2348. Table 3 and figure 3 show the same figures as in table 2 and figure 2, corrected according to the above formula, using a \( K_2 \) of 8 for meter no. 1365 and 5 for meter no. 2348. All points fall close to the theoretical and are also grouped closer to each other. At

<table>
<thead>
<tr>
<th>Standard</th>
<th>Respiratory Rate: 10</th>
<th>Respiratory Rate: 25</th>
<th>Respiratory Rate: 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1365</td>
<td>No. 2348</td>
<td>No. 1365</td>
<td>No. 2348</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>75</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>125</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>150</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>175</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>225</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

All figures corrected according to formula 1 in text (see fig. 3).
tidal airs above 100 cc., the above formula will reduce an over-all error of \( \pm 25 \) per cent to \( \pm 10 \) per cent for meter no. 1365 and \( \pm 35 \) per cent to \( \pm 7 \) per cent for meter no. 2348.

For greater accuracy, the calibration curves themselves (fig. 2) would have to be used, but then other factors, such as temperature, would have to be more carefully considered. For the usual clinical use, the over-all accuracy without correction is satisfactory, except perhaps for small children where low flows would be encountered.

The resistance of the Wright meters was found to be low in agreement with Byles. A rate of 39 strokes per minute and a tidal air of 500 cc. produced only 1.4 cm. of water pressure across the meter. Rarely would velocities greater than this be encountered clinically. The other requisites: compactness, unidirectional recording (by an ingenious use of axial versus radial flow), ease of connection, are all excellent. The readability is slightly impaired by its very compact size but a larger scale would increase the size and resistance of the meter. Cost is always a debatable point and will not be discussed here.

Summary. The Wright respiriometer is found to be an accurate, precise, compact, and easily used, ventilation monitor with very low resistance and true unidirectional recording. A correction formula is suggested for improved accuracy.

References


Addendum: Since this article was written, the meters have been observed to corrode and stick when allowed to get very wet in a circle system.

GADGETS

Nitrous Oxide-Oxygen "Flush" System

Drs. H. Rackow and E. Salanitre, and Mr. Arnold S. J. Lee of the Presbyterian Hospital in New York City noted occasions during the course of anesthesia when it is desirable to refill an empty breathing bag rapidly with an anesthetic mixture. The emergency \( \text{O}_2 \) high flow valve permits refilling with 100 per cent \( \text{O}_2 \) only and is not satisfactory for this purpose. A new instrument, the ratio-meter (designed by Mr. Lee), has been made which mixes \( \text{N}_2\text{O} \) and \( \text{O}_2 \) (or any two gases), indicates the proportion of each, and delivers the mixture at a very high flow. Installed in a Foregger anesthesia machine, it has been used satisfactorily in day to day clinical anesthesia for two years without requiring repair or readjustment. It does not interfere with the standard flow-meters or the emergency \( \text{O}_2 \) high flow valve. The latter is now used only when it is specifically desired to use 100 per cent \( \text{O}_2 \) to refill the breathing bag.

The pneumatic circuit of the ratio-meter is illustrated. \( \text{N}_2\text{O} \) and \( \text{O}_2 \) flow from opposite ends into a transparent inner tube \( T \), which has a slit \( S \), cut lengthwise along one side. A freely moving lightweight ball \( B \) is pushed by the two gases to a position where the pressures on both sides of the ball are equal. This position is determined by the ratio of the flow rates of the two gases entering the inner tube and the area of the slit through which each gas escapes. A transparent outer housing \( H \) surrounds the slit area of the inner tube and collects all the gases. The gas mixture then passes through the outlet tube of the housing to the breathing bag of the anesthesia machine.

Delivery is controlled by a "fail-safe" mechanism based on the \( \text{O}_2 \) supply pressure. A small push button gas switch connected to the \( \text{O}_2 \) supply line permits the \( \text{O}_2 \) supply pressure to control both an \( \text{O}_2 \) and a \( \text{N}_2\text{O} \) slave pressure regulator. The spring \( C \) exerts a pressure equivalent to about one p.s.i. on the diaphragm \( D \) in each regulator. Its action tends to move the diaphragm so as to close the valve \( V \). The \( \text{O}_2 \) supply pressure opposes this action and tends to move the diaphragm in the opposite direction to open the valve. If the pressure of the \( \text{O}_2 \) supply line falls below one p.s.i., both regulators would be closed by spring \( C \). This "fail-safe" principle