A Rapid Method for Analysis of Spirographic Tracings in Pulmonary Function Testing

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In recent years, pulmonary function testing has emerged from a primarily research activity carried on in only a few scattered laboratories, to a clinical function of steadily increasing importance in the diagnosis and management of pulmonary disease. This evolution has been in part due to the simplification of techniques and equipment. With increasing clinical employment of these techniques, it is important to simplify and accelerate these measurements. One of the time consuming aspects of such testing is the analysis of spiographic tracings. The methods described in this report are designed to provide more rapid analysis and measurements of spiograms without loss of accuracy.

The most widely used instruments for ventilatory measurements are the nine and 13½ liter Collins Respirometers, which provide an ink recorded spiographic tracing together with a cumulative record of ventilation by means of a second pen attached to a Reichert ventilograph.1 Tracings obtained with these instruments can provide the following measurements: resting minute ventilation and oxygen consumption, total vital capacity, timed expiratory volumes, inspiratory and expiratory flow rates, maximum breathing capacity, functional residual capacity by helium dilution, and bronchospirometry. Although the techniques as described are for use with Collins spirometers, they may easily be adapted for use with other instruments.

These techniques are based on a new "slide rule" which by a simple refinement of the Segal-Herschfus ruler2 provides more rapid and convenient measurements of spiographic tracings.

Method

The method consists of: (a) A multi-purpose "slide rule" for measurement of the various tracings, and (b) appropriate tables which con-

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1These slide rules may be obtained from Presco Plastics, Inc., Milwaukee, Wisconsin.
2The spirometer bells for the Collins nine and 13½ liter respirometer are now standardized at 20.73 cc./mm. and 41.27 cc./mm. respectively.
The author is indebted to Jacqueline Owenby, B.S. and Helen Delfeld, B.S. for their useful suggestions in connection with these methods.
vert the slide rule measurements to gas volumes corrected for temperature and barometric pressure.

The "slide rule" as illustrated in Figure 1 consists of a transparent plastic ruler* with four large vertical divisions each 32 mm. wide. This width corresponds to 12 seconds for the rapid kymograph speed of the Collins Respirometer and one minute for the slow kymograph speed of that instrument. The center two divisions have vertical rulings identical with the Segal-Herschfus ruler with 12 equal sub-divisions each representing one second at the rapid kymograph speed. The outer two divisions are ruled horizontally in millimeters, the left scale reading 0 to 150 mm. upward, and the right scale 0 to 150 mm. downward. The horizontal lines across the entire rule at each 50 mm. point are used to orient the ruler properly on the spirographic paper. Finally a slide with a hairline is provided which slips up and down the length of the ruler.

A second longer slide rule (Fig. 2) is available which differs only in that the millimeter scale reads from 0 to 300. This rule is designed primarily for use for measuring vital capacity tracings on the nine liter respirometer or similar spirometers with a small bell.

Two tables are utilized for a given spirometer. The tables shown are for the 13½ liter Collins spirometer but may just as easily be constructed for the Collins nine liter instrument or any other spirometer. Table I is used for vital capacity and oxygen consumption determinations and includes simply the bell factor (41.27 cc/mm for the 13½ liter instrument)* together with the temperature corrections as outlined by Comroe3

FIGURE 1: The 0-150 mm. pulmonary function slide rule superimposed upon a spirographic tracing. The tracing itself stands out distinctly because of the unlined paper used with this method.
to convert the gas volume to body temperature and pressure, saturated (BTPS). Table II is used in those measurements utilizing the ventilograph pen (resting minute ventilation and maximum breathing capacity) and incorporates: (a) the bell factor, (b) the ventilograph gear factor\(^1\) of the particular, instrument, (c) the factor “5” for converting the actual 12 second test to 60 seconds, thereby expressing the maximum breathing capacity in liters per minute, and (d) the temperature correction factor.\(^3\)

**Use of Method in Various Spirometric Determinations**

The techniques described below apply to tests performed with either the nine liter or 13½ liter Collins respirometer. The actual performance of these tests have been adequately described elsewhere.\(^2\)

For use of these methods with instruments other than Collins respirometers, it is necessary only to determine the actual time interval represented by 32 mm. on the kymograph tracings and the actual volume of air per millimeter of pen excursion (bell factor) for the particular spirometer. Appropriate tables may then be constructed for the particular instrument.

### TABLE I

**CONVERSION OF VITAL CAPACITY AND OXYGEN CONSUMPTION TRACINGS TO BTPS\(^*\) CORRECTED GAS VOLUMES (milliliters)**

for Collins 13½ liter Respirometer

Bell factor: 1 mm. of pen deflection = 41.27 ml.

<table>
<thead>
<tr>
<th>Pen Deflection in Mm.</th>
<th>Temperature of Spirometer gas in °C</th>
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<tr>
<td></td>
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<tr>
<td>ATPS**</td>
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</table>

*BTPS — Body temperature, pressure, saturated with water: correction factor according to Comroe.*

**ATPS — Ambient temperature, pressure, saturated with water (no temperature correction).**

*** — In order to save space, only the first three and last three lines of the table are shown here. The complete table will be available with reprints of this paper.
1. Total Vital Capacity Volume and Time

The vital capacity tracing is usually obtained with the rapid kymograph speed (32 mm. in 12 seconds). The slide rule is superimposed upon the tracing as shown in the upper right portion of Figure 3. The rule is placed so that the intersect just to the left of the upper zero mark (Fig. 3-A) is superimposed upon the tracing at the point of maximal inspiration just as the expiratory curve begins, and the ruler is correctly oriented. The slide hairline is then slipped down to the point of maximal expiration (Fig. 3-B) and the number of millimeters is read on the right hand mm. scale. With this millimeter reading and the temperature, the total vital capacity in millimeters corrected to BTPS may be rapidly obtained from Table I. While the ruler is still in place, the duration of the vital capacity expiration is read directly in seconds on the vertical lined scale reading from line “A” to point “B.” In Figure 3 this is exactly four seconds.

2. One, Two and Three Second Expiratory Volumes

The purpose of these measurements is the determination of the rapidity with which air can be expired. Thus the volume of air which can be ex-

FIGURE 2: The longer (0-300 mm.) slide rule used particularly with tracing made on the 9 liter spirometer.
pired in one, two and three seconds is measured and may be expressed both in actual volume and in per cent of the total vital capacity.4

For these measurements, the slide rule is placed so that intersect “A” (Fig. 3) is superimposed upon the point of maximal inspiration at the beginning of the expiratory curve just as for the total vital capacity. The hairline is then slipped down to the intersect between the one second vertical division and the expiratory tracing itself (Fig. 3-1) and a reading in millimeters is made on the right hand mm. scale. The hairline is then slipped down to the two second intersect (Fig. 3-2) and another similar reading taken. This is repeated for the third second intersect (Fig. 3-3). Each of these millimeter readings for the one, two and three second expiratory volume together with the temperature will provide the volume in millimeters corrected to BTPS by referring to Table I. The per cent of the total VC would be 1 sec. expiratory volume x 100 with a similar ratio for the two second and three second expiratory volumes.

Table II: Maximum Breathing Capacity Table

<table>
<thead>
<tr>
<th>Bell factor—41.27 cc./min.</th>
<th>Ventilograph gear factor—11.09</th>
</tr>
</thead>
</table>

The mm. in the left column refers to the mm. deflection of the ventilograph pen in a 12 second breathing period. The MBC value for this mm. deflection is read directly in liters per minute under the appropriate temperature column.

Formula for calculating table:

MBC in liters per min. = mm. of Ventilograph pen × Bell factor × Ventilograph gear deflection in 12 sec. (41.27) × 5 (to convert liters in 12 sec. to liters per minute) × Ventilograph gear correction factor (11.09)

<table>
<thead>
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<th>Ventilograph Pen deflection 12 sec. in Mm.</th>
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3. Oxygen Consumption

This test is performed with the slow kymograph speed (32 mm. = one minute), the tracing recording several minutes of breathing. The usual oxygen consumption baseline is drawn in the conventional manner connecting the expiratory points. The slide rule is then placed on the spirometer such that the intersect C (Fig. 3) on the slide rule is oriented on the paper and the hairline brought to the intersection of the $O_2$ baseline with the extreme vertical line (D) on the ruler. The reading is made on the left hand scale in millimeters and is corrected to a dry gas volume at $0^\circ$ C and 760 mm. Hg (STPD) by means of a correction factor obtained from a readily available nomogram.5

4. Maximum Breathing Capacity

The maximum breathing capacity (MBC) is performed as described by Motley et al6 employing a 12 second period of maximum voluntary hyperventilation with the kymograph drum moving 32 mm. in 12 seconds. For the MBC, the ventilograph tracing is used and a line is drawn defining the slope. Figure 4 shows the slide rule in place for this measurement. The lower left intersect just to the right of the zero mark (Fig. 4-E) is superimposed upon the beginning of the MBC ventilograph tracing. The hairline is then brought to the intersection of the ventilograph tracing and the extreme left vertical line on the rule (Fig.

![Diagram of the rule as used for vital capacity and oxygen consumption measurements.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=data/journals/01fuc/01309/01309 on 04/04/2017)

FIGURE 3: Diagram of the rule as used for vital capacity and oxygen consumption measurements.
4-F) and the number of millimeters read from the left hand scale. With this mm. reading and the temperature, the BTPS-corrected maximum breathing capacity can be read directly from Table II in liters per minute.

5. Resting Minute Ventilation

In this test the kymograph is run at the slow speed (32 mm. = 1 min.) for several minutes. The slope of the ventilograph tracing is inscribed, and the measurement made exactly as for the maximum breathing capacity. However, since the resting minute ventilation is measured on the slow speed, (1/5 of the rapid speed), the liters per minute as recorded in Table II must be divided by five. Calculation may be further simplified by measuring a two-minute period (Fig. 4, G-H) and dividing the value obtained from Table 2 by 10.

6. Maximal Midexpiratory Flow (Leuallen and Fowler)

The expiratory curve which appears steepest on gross inspection is selected. The zero mark of the right hand scale of the "slide rule" is placed at the peak of inspiration and the total vital capacity measured on the millimeter scale. This figure is divided by four to obtain the number of millimeters for 1/4 of the vital capacity volume (VC/4). With the zero mark of the right scale still superimposed upon the peak of

FIGURE 4: Diagram of the ruler as used for resting minute ventilation, maximum breathing capacity, and maximal mid-expiratory flow measurements.
inspiration, the number of millimeters of VC/4 is measured down the expiratory curve and a horizontal mark made with a thin pencil.

The zero mark of the left hand scale on the rule is then placed at the lowest point of expiration and the number of millimeters for VC/4 measured up the expiratory curve and a second horizontal mark inscribed. These steps have provided a point \( \frac{1}{4} \) of the way down from peak inspiration \( (J) \) and a second point \( \frac{1}{4} \) of the way up from maximal expiration \( (K) \).

A line is drawn connecting \( J \) and \( K \) (Fig. 4). The slope of this line expressed in liters per second is the maximal midexpiratory flow rate (MMEF). This "MMEF slope" may be measured as follows: The point, one second to the left of the 150 mm. line on the right hand scale (Fig. 4-L) is superimposed upon the "MMEF" slope line, and the ruler oriented with vertical lines. The point at which this slope crosses the "zero second" line (Fig. 4-M) is read in mm. on the left hand scale. The number of mm. together with the temperature provides from Table I a BTPS-corrected volume which is the MMEF expressed in liters per second.

If the slope is extremely steep, it might be necessary occasionally to use the 300 mm. slide rule (Fig. 2). On the other hand if the slope is comparatively flat, it is better to superimpose the ruler on the slope at the two second point and divide the millimeter reading by two.

**Discussion**

At the present time, pulmonary function tests are being carried out in hundreds of hospitals and increasingly in doctor's offices. One of the limiting factors in practical pulmonary function testing is still the time-consuming nature of both the testing techniques and the analysis of the spiromgrams. The methods herein described will not only expedite the analysis of the tracings, but will provide somewhat greater accuracy even in the hands of an average technician. An additional benefit of this "slide rule" technique is that by inscribing periodic vertical lines on the kymograph paper with the writing pen (for proper positioning of the slide rule), plain unruled paper may be substituted for the more expensive ruled kymograph paper. With the unruled paper, the tracings stand out more clearly and may be measured more easily in the absence of the confusing horizontal lines.

**SUMMARY**

1. A method is described for more rapid and efficient analysis of spiographic tracings utilizing a new transparent plastic slide rule and tables prepared for direct conversion of millimeter measurements of spiographic tracings into actual volumes and flow rates.

2. This method provides simpler and slightly more accurate measurements of spiographic tracings, eliminates much calculation, and allows the use of unlined and much less expensive spiographic paper in carrying out these tests.
Addendum

Recently, many pulmonary function laboratories have begun to use more rapid kymograph speeds, especially for more accurate evaluation of expiratory flow curves. A new Collins spirometer (Stead-Wells) provides a rapid kymograph speed of 32 mm. per second. The kymographs of the older Collins instruments may be converted to this rapid speed by simply substituting a more rapid motor for either of the two kymograph motors now in use.

The “slide-rule” is easily adaptable to these rapid speeds, since one large vertical division (32 mm.) would represent one second instead of twelve seconds. At this rapid speed, 0.5 second equals six small vertical divisions which permit an accurate measurement of the 0.5 second expiratory capacity.

RESUMEN

1. Se describe un método para realizar un análisis más rápido y eficiente de los trazos espirográficos usando una nueva regla plástica transparente, de deslizamiento, preparada para la conversión directa de las medidas en milímetros de los trazos espirográficos en los volúmenes verdaderos y medidas de las corrientes gaseosas.

2. Este método provee de medidas más sencillas y algo más exactas para los trazos espirográficos, elimina muchos cálculos y permite el uso de papel sin rayar y mucho menos caro para la espirografía al hacer estas lecturas.

ZUSAMMENFASSUNG

1. Es wird eine Methode beschrieben, die eine schnellere und leistungsfähige Analyse von spiographischen Aufzeichnungen unter Verwendung einer neuen transparenten Plastik-Gleitrolle und von Tabellen, die zur direkten Umwandlung der Millimetermessungen der spiographischen Aufzeichnungen in tatsächliche Volumina und Durchströmungswerte bestimmt sind.


REFERENCES