The Helium Closed Circuit Method for Measuring the Functional Residual Capacity

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The measurement of pulmonary ventilation by determination of the vital capacity, with its timed components, and the maximal breathing capacity is relatively simple. The various methods for determination of lung volumes, however, are for the most part complex and subject to considerable causes of error.

The use of helium as a foreign gas for measuring the functional residual capacity was first reported in 1941 by Meneely and Kaltreider.¹ A closed-circuit system, similar to that described by McMichael² using hydrogen, was used. In a subsequent publication³ these authors critically analyzed the method and compared it with other procedures. A principle disadvantage of the method pertained to the constant volume required in the circuit during rebreathing; this was accomplished by adding oxygen to the system as rapidly as it was consumed by the subject. It proved difficult in most instances to match accurately the subject's oxygen consumption, and rather complex correction factors were required for correcting volume changes.

Recently, Meneely, Ball, Kory, Roehm, Mabe and Kaltreider⁴ have simplified the method considerably by employing a closed-circuit system in which the subject rebreathes a mixture of helium and oxygen in air. Oxygen is not added to the circuit during the rebreathing period, and changes in helium concentration are continuously measured by a thermal conductivity unit.

It is the purpose of this report to describe our experiences with the simplified method (with minor modifications), and to present the results obtained in normal and emphysematous men.

Methods

1. Apparatus. The system is essentially the same as described previously except that a motor blower was substituted for the internal valves to provide mixing and a pump was inserted to provide for shunting the gas stream through a water saturator and the helium analyzer. A schematic diagram of the circuit is shown in Figure 1. The dead space in a 9 liter spirometer† was reduced by filling the area under the soda-lime cannister with paraffin to the top of the breathing tubes. The internal valves were removed. A motor blower‡ mixes the gases; a small aerator pump§ shunts part of the gas stream at a rate of 1.2 liters per minute through a water saturator and the thermal conductivity unit (helium

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katharometer), and returns the gas downstream. Helium enters the katharometer cells by diffusion; errors due to "flow" do not occur provided the flow-rate through the unit is less than two liters per minute. The concentration of helium is read in absolute units from an indicating meter furnished with the unit.

2. Procedure. The dead space of the circuit was measured as follows: with the mouthpiece valve open to room air, the spirometer bell was pushed down to empty the circuit as completely as possible; the valve opening was then closed with a tight rubber stopper. Free mixing in the breathing tubes could then occur. A short "zero line" was inscribed on the kymograph paper, and 600-700 ml of helium admitted through the stopcock. The exact amount of helium added was determined by measuring the length of the vertical line caused by the movement of the bell to the nearest 0.1 mm. This figure was then multiplied by the bell factor (20.73 ml/mm.). The blower was turned on, and when the helium and dead space air were completely mixed, as indicated by a steady reading on the meter, the helium concentration was recorded.

Calculations were as follows:

\[ \text{Dead space} = \left( \frac{\text{Amount of helium added}}{\text{Final helium concentration}} \right) - \text{helium added} \]

The mean of ten successive determinations of the dead space was 5630 ml, with a standard deviation of only 11.4 ml.

The accuracy of the meter was checked by connecting the circuit at the

†Cambridge Instrument Co.

FIGURE 1: Schematic diagram of the circuit employed. The respirometer has a capacity of nine liters, and the internal valves have been removed. Helium and oxygen are admitted through the two stopcocks. SL, soda-lime CO₂ absorber; D, kymograph drum; B, motor blower; V, valve at which subject is connected by a rubber mouthpiece; F, aerator pump; S, water saturator; K, katharometer block containing the thermal conductivity unit; M, helium indicating meter.
mouthpiece valve to a small spirometer in which a dead space of 4000 ml. had been accurately measured with water. Helium was then added to the circuit, and the contents mixed by pumping the spirometer bells. The dead space of the spirometer measured with helium was 4005, 4018, and 4010 ml. on three consecutive determinations.

For measurement of the the functional residual capacity (FRC), the spirometer circuit is emptied; the mouthpiece valve is left in the open position and a tight rubber stopper inserted. A short “zero line” is inscribed and 1.0 to 1.5 liters of helium admitted (the larger amount when a high FRC is expected). A helium line is then drawn by gently turning the drum, the length of this line being such that it remains visible for 8 to 10 minutes with the drum revolving at slow speed (32 mm/min.). The drum is returned to the starting point, and 1.5 to 2.0 liters of oxygen admitted (Figure 2). The blower and aerator pump are turned on; the helium concentration, which is usually in the range of 13 to 14 per cent, is read from the indicating meter when constant readings are observed.

The mouthpiece valve is quickly snapped to the closed position, the stopper removed, and a mouthpiece attached. The subject is then connected and breathes room air until the respirations are quiet and stable; the drum is started at slow speed, and at the end of a normal expiration, the valve is turned and the subject connected to the circuit.

During the rebreathing period changes in helium concentration are read from the meter at one minute intervals (the amperage is checked before each reading), and a final reading taken when the respiratory base line crosses the helium line. The helium concentration at this moment depends on the amount of helium originally present, the dead space in the circuit, and the amount of air present in the subject’s lungs at the time rebreathing of the helium mixture began. The calculation for the FRC is:

\[
FRC = \frac{\text{He added}}{\text{Final He Concentration}} - \frac{\text{Dead Space + Correction Factor}}{\text{He added} + \text{Dead Space + Correction Factor}}
\]

The correction factor is assumed to have a constant value of 200 ml., and is derived as follows: a) 100 ml. for a small amount of helium absorbed (15 ml.); b) 30 ml. for change in the respiratory quotient; and, c) 70 ml. for an average nitrogen increment in the circuit of 3 per cent higher than room air. The latter correction is necessary since the thermal

![Figure 2](image-url)
unit is calibrated for helium in air, and is slightly sensitive to nitrogen. The nitrogen concentration in the circuit immediately after the rebreathing period was measured in several instances with a nitrogen meter in normal and emphysematous subjects and found to vary between 2 and 5 per cent higher than room air.

The one minute meter readings are plotted as helium concentration against time, for evaluation of intrapulmonary gas mixing.

The FRC was measured in the sitting position in ten normal men, age range 26 to 43 years, mean 32 years and in 44 emphysematous subjects, age range 27 to 67 years, mean 52 years. Determinations were repeated at intervals of 20 to 30 minutes, and were required to check within 5 per cent. The vital capacity, inspiratory capacity, expiratory reserve volume, and maximal breathing capacity were determined with the same apparatus after removal of the soda-lime cannister. All values were corrected to body temperature and ambient barometric pressure, saturated with water vapor.\(^7\) Arterial blood studies were performed by standard methods with the Van Slyke Apparatus;\(^8\) pH was measured directly with a Cambridge Research Model pH Meter.

**Results**

The mean functional residual capacity in 10 normal subjects was 2.90 liters with a standard deviation of 0.75 liters. Additional data on these subjects, and comparison with results obtained by Hickam, Blair and Frayser\(^6\) in normal men with their helium open-circuit method are presented in Table I.

In the subjects with emphysema, the FRC ranged from 2.80 liters to

![FIGURE 3:](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21333/) The curves represent the mean values for 10 normal subjects, fifteen patients with emphysema and RV/TLC ratios less than 50 per cent, and twenty-one emphysematous patients with ratios greater than 50 per cent.
TABLE I

<table>
<thead>
<tr>
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<th>A</th>
<th>B</th>
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<tbody>
<tr>
<td>Number of Subjects</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Age in years</td>
<td>32 ± 5.7*</td>
<td>25.3 ± 2.6</td>
</tr>
<tr>
<td>Surface area (M²)</td>
<td>1.91 ± .17</td>
<td>1.92 ± .14</td>
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<tr>
<td>Vital capacity, liters</td>
<td>4.70 ± .66</td>
<td>4.80 ± .70</td>
</tr>
<tr>
<td>FRC, liters</td>
<td>2.90 ± .75</td>
<td>3.03 ± .37</td>
</tr>
<tr>
<td>Total lung capacity (TLC), liters</td>
<td>6.16 ± 1.11</td>
<td>6.16 ± .60</td>
</tr>
<tr>
<td>Residual volume (RV), liters</td>
<td>1.41 ± .45</td>
<td>1.37 ± .34</td>
</tr>
<tr>
<td>RV/TLC x 100</td>
<td>22.0 ± 1.38</td>
<td>22.3 ± 6.0</td>
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In column A are the data from the normal subjects in the present report. In column B are the values obtained by Hickam, Blair and Frayser* in normal seated men; the FRC was measured with an open-circuit helium method.

*Standard deviation.

8.2 liters, with a mean of 4.6 liters. For purposes of assessing relative severity, 36 patients in whom minute-to-minute changes in helium concentration were recorded were divided into two groups, depending on whether the ratio of the residual volume (RV) to the total lung capacity (TLC) was greater or less than 50 per cent. In Figure 3 are shown the mean values for the minute-to-minute changes in helium concentration during the rebreathing period in these two groups, as well as the mean values obtained in the normals. In the normals, the helium concentration began to rise between the second and third minute; a considerable difference is apparent in the curves obtained in the patients with emphysema.

FIGURE 4: Comparison of helium mixing curves in a normal and an emphysematous subject with similar FRC values.
The concentration of helium fell to lower values, and in the more severe group continued to fall until the fifth or sixth minute. Figure 4 shows the curves from a normal and an emphysematous subject with identical functional residual capacities, and similar minute volumes.

In the emphysematous subjects, the RV/TLC ratios as determined from the FRC were correlated with the vital capacity, maximal breathing capacity, and per cent arterial oxygen saturation at rest. The results are shown in Figure 5.

Discussion

The simplicity of the method described in this report, and the rapidity with which determinations may be made offer several advantages over other procedures. The equipment required is not unduly expensive, and technical help is not required for the analysis of gas samples. The difficulty of obtaining representative alveolar gas samples in the nitrogen open-circuit method has been stressed repeatedly; alveolar gas samples are not required in the present method. It is likely that helium, because of its high diffusability, gives more accurate values for intrapulmonary gas mixing and the FRC than do methods based on changes in nitrogen or oxygen concentrations.\(^5\)

The minute-to-minute changes in helium concentration which occur during the rebreathing period show an excellent correlation with the severity of the lung disease. Although intrapulmonary gas mixing evaluated in this manner is undoubtedly not as sensitive as that reported with the open-circuit helium procedure,\(^6\) it is sufficiently accurate for routine clinical use, and may serve as a qualitative guide for the presence of defective mixing.

The reproducibility of the method, and the problem of the "oxygen storage" effect which results from rebreathing a mixture in which oxygen concentration constantly decreases have been comprehensively analyzed by Meneely, Ball, Kory, Roehm, Mabe and Kaltreider.\(^7\) In 42 serial duplicate determinations the standard deviation for all values of the FRC was ±121 ml.; the standard error of a pair was less than ±86 ml. in 95 per cent of instances. According to these authors, the error introduced by the oxygen storage effect is insignificant, and attempts to correct for it may result in even larger errors.

![Figure 5: Comparative data between the lung volumes as obtained with the helium method and other tests of pulmonary function in the patients with emphysema. The bars represent mean values obtained from the same patients whose mixing curves are shown in Figure 3.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21333/)
SUMMARY
1. The simplified helium method for measuring the FRC is described and results obtained in normal and emphysematous subjects are presented.
2. Minute-to-minute changes in helium concentration during the rebreathing period may be plotted against time to represent qualitative changes in intrapulmonary gas mixing. These curves correlate well with the severity of the emphysema.
3. The method is sufficiently accurate for routine clinical use.

RESUMEN
1. Se describe un método simplificado de helio para medir el FCR y también los resultados obtenidos en sujetos normales y enfisematosos.
2. Cambios minuto a minuto en la concentración de helio durante el periodo de respiración a circuito cerrado, pueden planearse en relación al tiempo para representar los cambios cualitativos en las mezclas de gases intrapulmonares. Estas curvas están en correlación con la severidad del enfisema.
3. El método es suficientemente exacto para el uso clínico de rutina.

REFERENCES