CHAPTER - II

NORMS OF LUNG VOLUMES AND CAPACITIES FOR INDIANS

For a long time the tests for pulmonary function were made only in respect of various lung volumes and capacities. Actually the total lung capacity and its subdivisions are anthropometric measurements and do not give a correct evaluation of the function of the lung. However, they provide indices of available function as changes in the lung volumes and capacities may be caused due to certain malfunction and affection of the normal physiologic processes of the lung. Hence it is important to know the normal values of the lung volumes and capacities so that any abnormality can be detected and the possible cause for such deviation may be studied and interpreted.

Till recently a great difficulty in dealing with lung volumes and capacities was the inconsistency in terminology. Different authors and different text books have used diverse names for the same lung volumes and capacities. In order to remove this confusing state of affairs, a group of American Respiratory Physiologists met together under the chairmanship of Pappenheimer in 1950 and agreed on certain common names to be used. These terminologies have widely been accepted and are mostly used these days. In this report
these terminologies have been used and for removing any doubt both the old and the new versions are given below with definition.

Lung Volumes

The total lung capacity may be divided into four primary volumes without any overlapping with one another. These are mentioned below along with the old terms given in parenthesis.

(i) Tidal Volume - T.V. (Depth of Breathing) - It is the volume of air normally breathed in or out during each respiratory cycle.

(ii) Inspiratory Reserve Volume - I.R.V. (Complemental air) - It is the maximum volume of air that a man can inspire from the end point of normal inspiration.

(iii) Expiratory Reserve Volume - E.R.V. (Supplemental air, Reserve air) - It is the maximum volume of air that a man can expire from the end point of normal expiration.

(iv) Residual Volume - R.V. (Residual Capacity or air) - In spite of his best effort nobody can empty his lungs completely of air. A portion of air always remains there even at the end of maximum possible expiration. This volume of air is called residual volume.

Lung Capacities

Like volumes there are four capacities. Every one
of these capacities is made up of two or more of the primary volumes mentioned above.

(i) **Total Lung Capacity - T.L.C. (Total Lung Volume)** - As the name signifies, it is the largest amount of air that the lung can contain at the end of maximum inspiration. It is the sum total of all the four volumes mentioned above.

(ii) **Vital Capacity - V.C.** - It is the maximum amount of air that one can expire out after full inspiration. It is thus equal to the sum total of the tidal, inspiratory and expiratory reserve volumes.

(iii) **Inspiratory Capacity - I.C. (Complementary air)** - It is the maximum volume of air that one can inhale starting from the end point of normal expiration and represent the sum of the tidal and inspiratory reserve volumes.

(iv) **Functional Residual Capacity - F.R.C. (Functional residual air, Mid Capacity, Normal Capacity)** - It represents the volume of air that remains in the lungs at the end of normal resting expiration. It is the sum of expiratory reserve volume and residual volume.

The sub-division of the lung into various volumes and capacities as mentioned above may be schematically represented as follows in Fig. 1.
With the importance of the study of various lung volumes and capacities in the assessment of lung function duly established, investigations have been done in a number of laboratories all over the world (Hurtado & Bollar 1933, Baldwin et al. 1943, Gilson et al. 1953 and Comroe 1951) during the recent years.

But in India, there has not been any comprehensive study in this subject to elicit information about normal lung volumes and capacities in Indians of different age groups. There have been a few isolated reports from certain laboratories (Reddy and Sastry 1944, Telang and Bhagwat 1941, Bajaj and Millick 1959, Lundgren et al. 1953 and Singh 1960) but they are mostly restricted to students of younger age group and none of them covers all the sub-divisions of the lung capacity. Moreover, in many instances, the number of cases studied has not been large enough to draw a general conclusion. With a view to fill up this lacuna, a study
of the lung volumes and capacities of Indian males distributed over various age groups was undertaken, and reported here.

During the preparation of this paper, a special report (Rao et al. 1961) was published by the Indian Council of Medical Research on the same subject. It was found that this report was more comprehensive than others but this also did not use the recent terminology as mentioned before. The materials in this report, however, was duly considered while preparing this paper.

**Materials and Methods**

This study included observations on 101 healthy men taken partly from the scientific and office staff of the Central Mining Research Station and partly from outside organisations connected to mining industry. The subjects were categorised in different age groups over the range of 16 - 60 years. A short history of physical fitness was taken of each subject to eliminate persons having any respiratory trouble. The subjects were also examined radiographically for eliminating any abnormal case. They were distributed into age groups, at an interval of 5 years starting from 16 years of age. A record was taken of the physical build of the subjects like height and weight. The body surface area was determined according to the nomogram prepared by Banerjee and Sen 1957.
by modification of that proposed by Du Bois and Du Bois to suit subjects of Indian origin.

Table 1

Physical standards of the subjects in age groups at five years of interval.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Age group</th>
<th>No. of subjects</th>
<th>Age in yrs. Mean ± SD</th>
<th>Weight in Kg. Mean ± SD</th>
<th>Height in Cm. Mean ± SD</th>
<th>B.S.A. Sqm. Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16-20</td>
<td>8</td>
<td>16.40 0.54</td>
<td>50.30 5.73</td>
<td>162.13 4.42</td>
<td>1.59 0.095</td>
</tr>
<tr>
<td>2</td>
<td>21-25</td>
<td>12</td>
<td>23.33 0.93</td>
<td>54.40 7.60</td>
<td>162.77 4.04</td>
<td>1.64 0.064</td>
</tr>
<tr>
<td>3</td>
<td>26-30</td>
<td>26</td>
<td>28.08 1.49</td>
<td>59.60 9.72</td>
<td>165.92 7.42</td>
<td>1.72 0.168</td>
</tr>
<tr>
<td>4</td>
<td>31-35</td>
<td>10</td>
<td>32.10 0.96</td>
<td>62.53 8.18</td>
<td>167.60 4.45</td>
<td>1.78 0.125</td>
</tr>
<tr>
<td>5</td>
<td>36-40</td>
<td>17</td>
<td>37.94 1.36</td>
<td>60.71 16.48</td>
<td>164.67 5.70</td>
<td>1.74 0.133</td>
</tr>
<tr>
<td>6</td>
<td>41-45</td>
<td>12</td>
<td>42.75 1.23</td>
<td>61.13 9.02</td>
<td>162.28 7.28</td>
<td>1.73 0.192</td>
</tr>
<tr>
<td>7</td>
<td>46-50</td>
<td>9</td>
<td>48.20 0.96</td>
<td>61.40 15.13</td>
<td>162.83 6.90</td>
<td>1.72 0.220</td>
</tr>
<tr>
<td>8</td>
<td>51 and above</td>
<td>7</td>
<td>55.57 3.23</td>
<td>61.50 6.10</td>
<td>161.90 6.57</td>
<td>1.73 0.045</td>
</tr>
</tbody>
</table>

Table 1 gives a summary of the physical standards of the subjects included in the study. The observations were recorded before or 2-3 hours after the major meal and the subjects were given 15 minutes' rest before being put to the test. All tests to be performed were explained to the subjects very carefully and a trial run was demonstrated. They were also made fully conscious of the implication of the tests and the importance of their full co-operation in the success of this study and they did co-operate to the best of their abilities.
While the residual volume, tidal volume, inspiratory and expiratory reserve volumes and inspiratory capacity were recorded with the subjects seated comfortably on the chair, the vital capacity was taken in both sitting and standing position.

The apparatus used for the measurement of all the above lung volumes and capacities was a Jones Air Basal Metabolism Unit with the exception of the residual volume for which a Benedict-Roth Spirometer was used after making suitable adjustments.

As the Jones Air Basal Unit is a comparatively recent equipment and its use in our country is quite new, it is thought worthwhile to give a short description of the same for clear understanding. The very name 'Air Basal Unit' signifies that this unit is basically meant for the determination of basal metabolic rate. But its accurate system of recording graphically both time and volumes makes the apparatus suitable for other respiratory studies too. The actual photograph and a sectional diagram of the apparatus are given in Figs. IIa and IIb.

The apparatus consists of a large metal tank, with attached rubber bellows spirometer mounted on hinged panel. The sliding elevator assembly permits convenient adjustment for connection to patient on high or low bed, or in sitting
Fig. IIa - Photograph of the Jones Air Basal Unit in Operation.
or standing position. The 'Y' shaped tube in front directs the inspiratory and expiratory phases by its two limbs. The basalime chamber provided for the absorption of CO₂ during BMR determination is removed during lung function tests to eliminate the effect of CO₂ absorption in the volume thrust. The apparatus uses room air and hence no oxygen cylinder is necessary. There is a device to exhaust used air at the end of each test and fill with fresh air for the next one. For the recording of the tests, there is a Kymograph with downwardly movable plate and inkless stylus. The Kymograph can be fixed at the back of the main apparatus. The recording is done on the Kymograph by means of a "T" connector. The "T" connector has six holes or volume connections. The movement of the Kymograph plate is operated electrically and can be regulated by the timer at the side of the Kymograph. The measurement of the bellows' expansion or contraction as indicated by the horizontal deflection of the stylus is computed on the basis of 10%, for each 1/8th inch shift of the volume connection used, e.g. when the volume pin is set at 1600 ml., then each 1/8th inch deflection is equivalent to 160 ml. at BTPS*. The inkless recordings are made on the specially calibrated papers supplied with the instrument and

* BTPS = Body Temperature and Pressure Saturation.
set on the kymographic plate. The Fig. III presents a typical sample of our actual recording. For the purpose of the present study, the volume connection at 2000 ml. was used.

Fig. III - Actual recording of the lung volumes and capacities from the use of Jones air basal unit. TV = Tidal volume; IC = Inspiratory capacity; ERV = Expiratory Reserve Volume; VC = Vital Capacity; EV = Exercise Ventilation. The movement of the Kymographic plate was 1" / min., but for EV it was 1/2" / Sec.
Besides records of various lung volumes and capacities at resting condition it may be found from the right half of the above diagram that with increase of body activity, the frequency of respiration and tidal volume (shown as Exercise Volume - EV) both increase. The inspiratory and expiratory reserve volumes correspondingly decrease. This is due to enhanced body metabolism and consequent greater demand for supply of oxygen to the tissue cells and removal of corresponding increased amount of carbon dioxide produced.

As mentioned above, for residual volume estimation, a Benedict-Koeth Spirometer was used with certain adjustment.

For all the items of measurements mentioned above, the subject was connected to the apparatus through a mouth-piece and breathed through mouth as the nasal path was blocked by nose clip. Only for vital capacity, the subject was asked to take maximum inspiration, then close the nose by one hand and finally to expire fully with maximum effort through the adaptor tube.

The residual volume is the only one of the primary lung volumes, that cannot be measured directly. There are two methods namely, the open circuit and the closed circuit. We used the closed circuit method and considered nitrogen as the test gas. The modified method of Christie 1932 was
All the gas samples were analysed by Haldane Gas Analyzer to get the percentage of Nitrogen. The calculation is based on the degree of dilution of alveolar nitrogen before and after the test as shown below:

The volume of nitrogen in the lung-spirometer system before and after test, remained the same. During re-breathing in the course of the experiment nitrogen in the lungs and spirometer is redistributed and comes to equilibrium. The residual volume is calculated at BTPS, in the following manner.
After making the correction for temperature and pressure the equation turns out as follows:

\[ RV = \frac{273 + t^\circ C}{273 + t^\circ C} \times \frac{PB - Fwt}{PB - 47} \times \frac{V_{s2} N_{s2} - V_{s1} N_{s1}}{N_L - N_{s2}} \]

where \( RV \) = Residual Volume, \( PB \) = barometric pressure, 
\( t^\circ C \) = Temp. of the spirometer gas; \( N_L \) = Initial percentage of nitrogen in the residual air.  
\( Fwt \) = aqueous tension at \( t^\circ C \); \( V_{s1} \) at \( t^\circ C \) = Volume of gas in the spirometer before test.  
\( V_{s2} \) = Volume of gas in the spirometer after test.  
\( N_{s2} \) = Final percentage of nitrogen in the spirometer.  
\( N_{s1} \) = Initial percentage of nitrogen in the spirometer.  

Theoretically \( V_{s1} \) and \( V_{s2} \) should be equal, though in practice there may be slight difference in the two.

A single breath technique for measurement of residual volume by using pure oxygen has been developed in this laboratory. This will be described in a separate chapter later (Chapter III).

Results

The physical characteristics of the subject under study have already been presented in Table 1. Fig. V shows the average and median values of weight and height in different
age groups. It has been observed that the average and the median values do not differ much.

All the volumes and capacities obtained from the experiment with Jones Air Basal Unit were at normal body temperature (37°C), ambient barometric pressure, saturated with water vapour (BTPS). Conversion for BTPS was required only for residual volume for which the Benedict-Roth Spirometer was used. Table 2 presents a summary of the total lung capacity and its different sub-divisions in
TABLE - 2

Iodol lung capacities and its different sub-divisions in different age groups of healthy Indian males

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Age Group</th>
<th>No. of Subject</th>
<th>1L LIT</th>
<th>2L LIT</th>
<th>3L LIT</th>
<th>4L LIT</th>
<th>5L LIT</th>
<th>6L LIT</th>
<th>7L LIT</th>
<th>8L LIT</th>
<th>9L LIT</th>
<th>10L LIT</th>
<th>11L LIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16 - 20</td>
<td>8</td>
<td>0.52</td>
<td>0.09</td>
<td>1.92</td>
<td>0.61</td>
<td>1.35</td>
<td>0.62</td>
<td>0.94</td>
<td>0.26</td>
<td>2.32</td>
<td>0.44</td>
<td>2.13</td>
</tr>
<tr>
<td>2</td>
<td>21 - 25</td>
<td>12</td>
<td>0.70</td>
<td>0.21</td>
<td>1.69</td>
<td>0.38</td>
<td>1.24</td>
<td>0.25</td>
<td>0.93</td>
<td>0.19</td>
<td>2.16</td>
<td>0.33</td>
<td>2.44</td>
</tr>
<tr>
<td>3</td>
<td>26 - 30</td>
<td>26</td>
<td>0.71</td>
<td>0.24</td>
<td>1.77</td>
<td>0.40</td>
<td>1.27</td>
<td>0.34</td>
<td>1.12</td>
<td>0.37</td>
<td>2.38</td>
<td>0.49</td>
<td>2.36</td>
</tr>
<tr>
<td>4</td>
<td>31 - 35</td>
<td>10</td>
<td>0.66</td>
<td>0.19</td>
<td>1.91</td>
<td>0.37</td>
<td>1.59</td>
<td>0.38</td>
<td>1.02</td>
<td>0.37</td>
<td>2.62</td>
<td>0.34</td>
<td>2.43</td>
</tr>
<tr>
<td>5</td>
<td>36 - 40</td>
<td>17</td>
<td>0.66</td>
<td>0.22</td>
<td>1.88</td>
<td>0.40</td>
<td>1.26</td>
<td>0.28</td>
<td>1.24</td>
<td>0.28</td>
<td>2.50</td>
<td>0.32</td>
<td>2.28</td>
</tr>
<tr>
<td>6</td>
<td>41 - 45</td>
<td>12</td>
<td>0.59</td>
<td>0.14</td>
<td>1.89</td>
<td>0.31</td>
<td>1.20</td>
<td>0.43</td>
<td>1.19</td>
<td>0.43</td>
<td>2.38</td>
<td>0.43</td>
<td>2.38</td>
</tr>
<tr>
<td>7</td>
<td>46 - 50</td>
<td>9</td>
<td>0.57</td>
<td>0.07</td>
<td>1.68</td>
<td>0.38</td>
<td>1.26</td>
<td>0.37</td>
<td>1.35</td>
<td>0.42</td>
<td>2.60</td>
<td>0.44</td>
<td>1.96</td>
</tr>
<tr>
<td>8</td>
<td>51 above</td>
<td>7</td>
<td>0.77</td>
<td>0.10</td>
<td>1.13</td>
<td>0.35</td>
<td>1.03</td>
<td>0.38</td>
<td>1.36</td>
<td>0.33</td>
<td>2.38</td>
<td>0.33</td>
<td>2.09</td>
</tr>
</tbody>
</table>
Table 3
Vital capacity, absolute, per sq.m. of BSA, per Kg. of body weight and per cm. of standing height both in sitting and standing positions in healthy INDIAN subjects.

<table>
<thead>
<tr>
<th>Age group, No. of subs.</th>
<th>Posture</th>
<th>VC in Lit. Mean ± SD</th>
<th>VC/Sqm. of BSA in Lit. Mean ± SD</th>
<th>VC/Kg. of body weight in ml. Mean ± SD</th>
<th>VC/cm. standing height in ml. Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-20</td>
<td>Sitting</td>
<td>4.02 ± 0.40</td>
<td>2.47 ± 0.29</td>
<td>78.9 ± 10.4</td>
<td>24.7 ± 4.3</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.82 ± 0.53</td>
<td>2.35 ± 0.43</td>
<td>75.6 ± 11.4</td>
<td>23.1 ± 2.9</td>
</tr>
<tr>
<td>21-25</td>
<td>Sitting</td>
<td>3.72 ± 0.38</td>
<td>2.25 ± 0.32</td>
<td>69.7 ± 8.7</td>
<td>22.3 ± 3.5</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.82 ± 0.42</td>
<td>2.27 ± 0.25</td>
<td>68.7 ± 9.5</td>
<td>22.8 ± 2.9</td>
</tr>
<tr>
<td>26-30</td>
<td>Sitting</td>
<td>3.74 ± 0.49</td>
<td>2.18 ± 0.24</td>
<td>64.7 ± 10.1</td>
<td>22.6 ± 2.5</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.64 ± 0.39</td>
<td>2.15 ± 0.34</td>
<td>63.6 ± 8.2</td>
<td>21.9 ± 3.0</td>
</tr>
<tr>
<td>31-35</td>
<td>Sitting</td>
<td>4.05 ± 0.40</td>
<td>2.28 ± 0.30</td>
<td>65.3 ± 10.1</td>
<td>24.6 ± 3.1</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>4.15 ± 0.47</td>
<td>2.34 ± 0.16</td>
<td>66.9 ± 9.7</td>
<td>25.3 ± 3.1</td>
</tr>
<tr>
<td>36-40</td>
<td>Sitting</td>
<td>3.78 ± 0.46</td>
<td>2.12 ± 0.20</td>
<td>62.7 ± 10.7</td>
<td>21.6 ± 1.3</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.80 ± 0.49</td>
<td>2.18 ± 0.17</td>
<td>64.1 ± 10.5</td>
<td>23.0 ± 1.5</td>
</tr>
<tr>
<td>41-45</td>
<td>Sitting</td>
<td>3.61 ± 0.43</td>
<td>2.09 ± 0.25</td>
<td>61.1 ± 10.9</td>
<td>21.1 ± 2.3</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.60 ± 0.47</td>
<td>2.13 ± 0.29</td>
<td>61.2 ± 10.7</td>
<td>22.5 ± 2.4</td>
</tr>
<tr>
<td>46-50</td>
<td>Sitting</td>
<td>3.06 ± 0.42</td>
<td>1.80 ± 0.71</td>
<td>57.5 ± 14.5</td>
<td>21.2 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>3.50 ± 0.37</td>
<td>2.04 ± 0.38</td>
<td>58.5 ± 13.9</td>
<td>21.6 ± 2.1</td>
</tr>
<tr>
<td>&gt;1-above</td>
<td>Sitting</td>
<td>2.92 ± 0.43</td>
<td>1.70 ± 0.29</td>
<td>48.7 ± 12.7</td>
<td>17.9 ± 2.4</td>
</tr>
<tr>
<td></td>
<td>Standing</td>
<td>2.94 ± 0.37</td>
<td>1.78 ± 0.27</td>
<td>51.2 ± 12.7</td>
<td>19.0 ± 2.3</td>
</tr>
</tbody>
</table>
different age groups. The relation between age and total lung capacity and its sub-divisions expressed as total and as per sqm. of BSA are projected in Figs. VIa and VIb respectively. Table 3 shows the vital capacity both in

sitting and standing positions as a whole as well as per sqm. of BSA, per kg. of body weight and per cm. of standing height.

The respiratory rates as obtained in the experiment spread over a range of 12/min. to 24/min. and the minute ventilation over a range of 6 lit/min. to 17 lit./min.
Discussion

It has already been mentioned that data on lung capacity and its sub-divisions is a good adjunct in the assessment of lung function and is of diagnostic and therapeutic value. But it is rarely possible to use it as the sole guide towards a correct diagnosis of the malady of the lung. This is because of the large variation in the lung volumes and capacities from individual to individual even in the normal group. It may, sometimes be as great as ± 20% of the group mean value and hence this limitation in their usage. However, determination of the lung volumes and capacities is widely accepted as the best measure of the pulmonary elasticity present and of special significance in the appraisal of pulmonary emphysema and the like. For example, the vital capacity of any particular individual should not normally reduce by more than 200 c.c. over a considerable period of time (Barach and Bickerman 1957). If it reduces by more than 15% he should be carefully examined medically for some diseased condition interfering directly or indirectly with the function of the heart or lungs. It should be mentioned in this connection that while comparing results of different measurements it must be made certain that they have been obtained under similar conditions.
(supine, prone, sitting or standing position of the subjects) as otherwise the comparison will be useless. Moreno and Lyons (1961). The results in Table 2 show the general trends of group variation in the various lung volumes and capacities with age. It will be found that maximum values have been reached by 4th decade, after which they normally start reducing with age. In the case of residual volume it is found to increase with age. These relations are more clearly illustrated in Fig. VII.

Vital capacity which is considered to be the
most important of the lung capacities as an index of the lung efficiency constitutes about 80 per cent of the total lung capacity till about the middle of the 4th decade and then gradually decreased reaching below 70 per cent after 50. Knowles (1959) mentions that in U.S.A., the vital capacity normally reduces to approximately 60 per cent of the lung capacity in the 8th decade.

Baldwin et al. 1948, have suggested a formula for predicting the total lung capacity which on modification on the basis of our experience turns out as follows. This is expected to suit better to Indian subjects.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>16-35</th>
<th>36-45</th>
<th>46-50</th>
<th>51-above</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLC (litre)</td>
<td>$\frac{VC}{0.80}$</td>
<td>$\frac{VC}{0.75}$</td>
<td>$\frac{VC}{0.72}$</td>
<td>$\frac{VC}{0.70}$</td>
</tr>
</tbody>
</table>

As determination of residual volume is difficult and may not be possible for all the laboratories, it may conveniently be predicted from the total lung capacity as obtained from the above formula by deducting the vital capacity which is much easier to determine directly.

Regarding the relation of the various lung volumes and capacities to the different physical indices like height, weight and body surface area, there has been much discussion by various authors from all over the world.
Rao et al. 1961, have discussed the matter in detail and they mention that the best correlation is obtained with body height, next comes the body surface area and then body weight. In this study, however, relation has been drawn with the body surface area and this has been presented in Fig. VIB. The vital capacity per unit body surface area for various ages upto 50 shows practically a steady relation. Only for vital capacity its relation has been computed with all the three physical characteristics namely, body surface area, body height and body weight. The result, presented in Table 3 shows these relations for sitting and standing vital capacities. The difference in the sitting and standing vital capacities, groupwise, is also not great. It is found from this table that vital capacity when expressed in this form is maximum in the age group of 16-20 though as a whole it is found consistently high upto the age group of 31-35. However, it is proposed to deal in detail with the relationship of vital capacity with the various physical characteristics in a separate chapter (Chapter IV).

Conclusion

Lung volumes and capacities, though by themselves may not be conductive to any definite conclusion in the diagnosis and the therapeutics of any involvement of the lung or heart they may, however, be helpful in giving
certain clues towards that end. This is why they are being more and more used by clinicians and industrial physiologists. They are of particular importance in determining the disability developed in patients due to some diseases of the lungs supposed to be of certain known origin. For example, in pneumoconiosis developed amongst miners due to dust inhalation, determination of lung volumes and capacities may be of particular importance. However, for any of these applications, it is essential that normal range of values for healthy people are available for finding out the abnormality and its interpretation. Standards currently available are mostly of foreign origin and are not properly applicable to Indian subjects. Even in the same country standards available from different sources vary depending on the condition under which they are developed. Each laboratory has eventually to settle upon its own choice with its own modifications as it finds necessary. It is unfortunate that most of the normal standards are based upon a paucity of data. This is particularly true of India. The report of Rao et al., 1961, is perhaps the only one which is based on certain statistical figures. The present study is expected to put it on a firmer basis and will provide a suitable yard stick.
for work on lung physiology. The standard provided by this study will also help this laboratory in its future work in connection with the respiratory involvement in pneumoconiosis amongst miners.

Summary

The total lung capacity and its various subdivisions namely Tidal Volume, Inspiratory and Expiratory Reserve Volumes, Vital Capacity, Inspiratory Capacity and Functional Residual Capacity were determined amongst healthy Indian males of different age groups by using 'Jones Air Basal Metabolism Unit'. Residual Volume was determined using a 'Benedict-Roth' Spirometer by modification and suitable adaptation. The results are discussed and their importance in the assessment of respiratory function stressed.

REFERENCES


the use of closed circuit helium dilution method for the estimation of residual volume. In this laboratory also modified method of Christie was used as reported earlier in Chapter II. At that time, it was felt that both the open circuit and closed circuit nitrogen dilution methods are time consuming and laborious and at the same time require good understanding and co-operation from the subject. It was, therefore, thought worthwhile to look for a suitable short method which can be used without causing much inconvenience to the subjects.

In a critical study of the various methods in vogue, it was clear that the principle underlying the estimation of residual volume is mainly based on the extent of dilution of the test gas (nitrogen present in the residual air, or helium supplied with air at a known concentration). Thus if a knowledge of the extent of dilution of the test gas due to the mixing of the residual air and inhaled gas is the main requirement for calculating the residual volume, it is felt that there is no reason why the single breath technique which is used for estimating the diffusion and distribution of gas in the lung could not be used with suitable modification for the purpose of estimating the
Table 4
The physical characteristics of the subject under investigations

<table>
<thead>
<tr>
<th>Nature of subjects</th>
<th>No. of subjects</th>
<th>Age in yrs. Mean ± SD</th>
<th>Weight in Kg. Mean ± SD</th>
<th>Height in Cm Mean ± SD</th>
<th>BSA in sqm Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory worker</td>
<td>13</td>
<td>29.00 2.54</td>
<td>55.69 8.02</td>
<td>164.57 3.98</td>
<td>1.66 ± 0.15</td>
</tr>
<tr>
<td>Mine Worker</td>
<td>17</td>
<td>25.00 4.50</td>
<td>47.62 1.88</td>
<td>161.02 5.22</td>
<td>1.54 ± 0.10</td>
</tr>
</tbody>
</table>

A is the Douglas bag, connected to a three way plastic valve Y of low resistance through an aluminium stock cock. One end of this valve is connected to the spirometer B. The side end is connected to the mouth-piece M through a 3-way aluminium stop cock Z. The side opening of Z leads to the atmosphere and is used for collection of gas samples for analysis. The space in the connecting links between stop cocks and the valves is left at the minimum. The Douglas bag is filled with pure oxygen and the whole system upto Z is flushed with this gas and closed at Z. The subject is now connected to the system through the mouth-piece M. He is asked to expire to the maximum and the expired air passes out in the atmosphere through the opening of the stop cock K. A sample of the breath from the last portion of the expired
air is taken (Sample P) through the side opening of Z. Its analysis will give the composition of the residual air. The subject is now connected to the Douglas bag. He is asked to inspire to the maximum and then hold the breath. The connection to the Douglas Bag is now closed

and the subject is connected to the spirometer B through the proper adjustment of the stop cock K. After 20 seconds of breath hold, he is asked to expire to the maximum and the expired air is collected in the spirometer. A small sample (Sample Q) of the same is collected towards the end
of the expiration through the side opening of Z. The volume of the expired air as collected in the spirometer together with the sample Q gives an estimate of the volume of oxygen that the subject had inhaled. The amount of nitrogen in the samples P and Q gives respectively the concentrations of nitrogen in the residual air of the subject and after its dilution due to inhalation of oxygen. The gas analysis was done in a Scholander micro gas analyser. Correction was also made for any small amount of nitrogen present in the oxygen used.

Theory and Calculation

At the forced end-expiratory level, the lung of a person contains only the residual air. Let RV be the residual volume. If FN1 is the percentage of nitrogen in it, then the amount of nitrogen present in it will be

\[ \frac{RV x FN_1}{100} \]

Now suppose the subject inhales oxygen, the volume of which is SV, then the total volume of gas in the lung will be \( RV + SV \). If the percentage of nitrogen in this volume = FN2, then the amount of nitrogen present in the lung at this stage = \( \frac{(RV + SV) x FN_2}{100} \). But the amount of nitrogen at the beginning and end of oxygen inspiration remains the same and is not likely to be affected during breath holding.
or \[ RV = \frac{SVFN_2}{FN_1 - FN_2} \]

After making necessary correction required for expressing \( RV \) at BTPS, the relation stands as

\[
RV = \frac{273 + 37^\circ C}{273 + t^\circ C} \times \frac{PB - Pwt}{PB - 47} \times \frac{SVFN_2}{FN_1 - FN_2}
\]

where \( t \) = Temperature of the gas in the spirometer.

\( Pwt \) = Aqueous tension at \( t^\circ C \).

\( 47 \) = Aqueous tension at body temperature.

\( 37^\circ C \) = Body temperature in centigrade.

\( PB \) = Barometric pressure.

It is to be noted here that the nitrogen present in the dead space at the time prior to oxygen inhalation was not taken into consideration for the purpose of this calculation, as it is considered not to affect the result to any appreciable extent.

As the nitrogen percentage of the residual air is practically the same as that in the normal air, \( FN_1 \) may be taken as 80 for routine purpose. However, it is always better to analyse the alveolar air as stated before if more precision is desired.
Results

Initially the residual volumes were determined for five subjects by both the closed circuit multiple breath nitrogen dilution method reported previously as well as the presently described single breath technique. Table 5 presents a comparison of the data obtained by the two methods for each subject.

Table - 5

A comparison of Residual Volume as determined by single breath technique with those obtained by modified method of Christie.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Age in years</th>
<th>RESIDUAL VOLUME (LIT.)</th>
<th>Single breath method</th>
<th>Modified Christie's method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>32</td>
<td>1.381</td>
<td></td>
<td>1.250</td>
</tr>
<tr>
<td>2.</td>
<td>27</td>
<td>1.119</td>
<td></td>
<td>1.120</td>
</tr>
<tr>
<td>3.</td>
<td>30</td>
<td>0.961</td>
<td></td>
<td>0.930</td>
</tr>
<tr>
<td>4.</td>
<td>28</td>
<td>1.261</td>
<td></td>
<td>1.013</td>
</tr>
<tr>
<td>5.</td>
<td>34</td>
<td>1.304</td>
<td></td>
<td>1.262</td>
</tr>
</tbody>
</table>

The method was then extended to 6 more subjects of the same socio-economic group. As the results were encouraging, 17 healthy miners of the same age group were also included in the study. Table 6 presents a summary of the results compared to those reported earlier for the same age group and also to those reported by Kasliwal et.al. 1964, by using closed circuit helium dilution method.
### Table - 6

Residual volumes as found by single breath nitrogen dilution technique in comparison to those reported by other Indian workers employing multiple breath technique.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>No. of Group subjects</th>
<th>Residual volume Mean (lit)</th>
<th>± S.D.</th>
<th>Age Group</th>
<th>No. of Group subjects</th>
<th>Residual volume Mean (lit)</th>
<th>± S.D.</th>
<th>Age Group</th>
<th>No. of Group subjects</th>
<th>Residual volume Mean (lit)</th>
<th>± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>26-35</td>
<td>36</td>
<td>1.092</td>
<td>0.371</td>
<td>26-35</td>
<td>10</td>
<td>1.33</td>
<td>0.32</td>
<td>20-35</td>
<td>17</td>
<td>1.257</td>
<td>0.362</td>
</tr>
<tr>
<td>26-35</td>
<td>13</td>
<td>24.34</td>
<td>0.166</td>
<td>20-35</td>
<td>17</td>
<td>1.227</td>
<td>0.074</td>
<td>20-35</td>
<td>17</td>
<td>1.257</td>
<td>0.362</td>
</tr>
</tbody>
</table>

Reported in Chapter II Kasliwal et al. (1964) Modified Christie's Closed circuit Helium Dilution method Present method of single breath N₂ dilution
Discussion

There appears to be no work reporting the use of the single breath technique for determination of residual volume. The most important consideration in the application of the single breath technique for the determination of residual volume is to ensure a uniform dilution of the residual air, so that the alveolar sample collected towards the end of the forced expiration after breath hold represents the true composition of the gas in the lung. This eliminates the error likely to be introduced due to the dead space volume being mixed up with the gas collected in the spirometer. The spirometer volume together with the volume of the gas sample collected for analysis gives the volume of oxygen inhaled by the subject. The nitrogen percentage in the sample collected gives the percentage of nitrogen in the lung gas at the time of the expiration. Regarding the question of uniform mixing of the gas in the lungs, it is expected that a breath-holding for 20 seconds as has been done in this experiment will be enough for such mixing. It has been shown by Roos et al. 1955, that a non-linear clearance curve of lung gas becomes linear when the breath is held for 20 seconds after each inspirations. Baarsma 1943, has also explained that in 20 seconds breath holding, the differences in the regional gas concentra-
From a comparison of the residual volumes obtained by following Christie's method and the present method on the same subjects (Table 5) it will be found that the results are quite comparable and in most cases a bit higher in the single breath technique.

Kasliwal et al. 1964, appears to be the first Indian workers using closed circuit helium dilution method for the determination of residual volume. The figures reported by them are slightly higher than those reported by other Indian workers using nitrogen as the test gas (Table 7). The results obtained in the present study by using single breath technique is very close to those reported by them for the same age group (Table 6). This has been found true both in the case of laboratory workers and healthy miners. It is thus concluded that this method is quite comparable to others and is simple enough for use with advantage.

Summary

Residual volume is usually determined by either the closed circuit or the open circuit multiple breath dilution method using helium or alveolar nitrogen as the test gas. There is no record of its being determined by the single breath technique. An experimental design has been described and used to determine residual volume by using single
breath technique. The subject is required to inspire oxygen fully after complete expiration and then hold the breath for 20 seconds. The analysis of the expired gas after breath hold at the end expiratory level of forced expiration gives the dilution of nitrogen present in the residual air and the expired volume gives the amount of oxygen inhaled. From these two and the concentration of nitrogen in the normal alveolar air, the residual volume of the lung is calculated. Determination has been made of this lung volume for 13 healthy young Indian laboratory workers and 17 healthy Indian miners. The results were found to compare well with those reported by other Indian workers by the other conventional methods.

REFERENCES


