Relationship of Height to Lung Volume in Healthy Men*

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The accurate definition of physiologic normality in man is a prerequisite to quantitation of disease. It has long been known that the total lung volume or a subdivision thereof of a person has limited significance as an isolated measurement unless it can be compared to a normal value. Although the ranges of normality of the various subdivisions, when expressed as a percentage of the normal total capacity, have been established, one still must know what the total capacity should be under normal conditions before actual values of it and its subdivisions can be evaluated in terms of being normal or abnormal. Ever since Hutchinson first reported his extensive study of the vital capacity of man, many attempts have been made to define the correlations between vital capacity (and later, total capacity) and various physical measurements in the hope that it would be possible to predict accurately the normal lung volumes from certain physical measurements. Hutchinson correlated vital capacity with standing body height. In addition, stem height, weight, surface area, circumference and volume of the thorax, radiologic lung area or volume, age or any combination of these measurements has been utilized in predicting lung volumes. Most attempts have been made at trying to describe a linear correlation between body build and lung volume. Good correlations pertained over only limited ranges. To overcome this, formulas utilizing multiple linear correlations have been derived.

Kelly, in a study of vital capacity of boys and girls, first identified the relationship between vital capacity and the cube of height. Bateman later expressed the relationship of the total lung volume and its subdivisions to the third power of the body height of adults of average stature. Subsequently, Morse and associates, Helliesen and co-workers, and Engström and associates described this relationship in boys and girls.

It is the purpose of this study to determine if this relationship still pertains when the height levels are extended beyond the ranges herefore reported.

Methods

Measurements of vital capacity and total lung capacity were made on 39 healthy male physicians and laboratory workers ranging from 21 to 44 years of age. Older persons were not included in order to avoid the well-known effects of age on vital capacity. In addition to men of average height, men were selected who were unusually tall, including 15 who

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were 6 feet (183 cm.) or more in height. Determinations of vital capacity only were done on 37 additional men, including 10 professional basketball players. In these last 10 men, vital capacity was measured with the subjects standing; otherwise, measurements were made in the seated position and the men were not fasting.

The total capacity was measured by adding the vital capacity, obtained by use of a Benedict-Roth type of spirometer, to the residual volume. The latter was determined by a modification, previously described, of Darling's open-circuit, nitrogen-elimination method. All volumes are expressed at BTPS (body temperature, ambient pressure, saturated).

### Results

The results are listed in the accompanying table, along with Bateman's compilation of his and Birath's data on young men, and

<table>
<thead>
<tr>
<th>Authors</th>
<th>Mean age (range)</th>
<th>Mean height (range)</th>
<th>Total capacity</th>
<th>Vital capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bateman-Birath</td>
<td>28 (18-39)</td>
<td>175.9 (164-186)</td>
<td>1.177 0.141</td>
<td>0.896 0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28 0.027</td>
<td>28 - -</td>
</tr>
<tr>
<td>Helleisen</td>
<td>11.0 (5-17)</td>
<td>147.6 (110-184)</td>
<td>1.138 0.147</td>
<td>0.872 0.021</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.021 0.016</td>
<td>13.0 13.5</td>
</tr>
<tr>
<td>This report</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total capacity</td>
<td>31 (21-44)</td>
<td>180.4 (164-198)</td>
<td>1.216 0.129</td>
<td>0.908 0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.103 0.021</td>
<td>76 10.7</td>
</tr>
<tr>
<td></td>
<td>31 (22-41)</td>
<td>184.3 (164-206)</td>
<td>0.211 0.021</td>
<td>0.012 10.7</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td></td>
<td>0.018 0.008</td>
<td>0.018 0.008</td>
</tr>
</tbody>
</table>

*Predicted as VC=0.9 Ht³ and TC=1.18 Ht³ (VC and TC in liters; Ht in meters).

N is number of subjects.

*FIGURE 1: Relationship of lung volumes to body height.*
FIGURE 2: Relationship of lung volumes to body height. Same data as in figure 1, but on a double logarithmic scale.

FIGURE 3: Relationship of lung volumes and body height. Comparison of mean values from a number of sources.
measurements on boys by Helliesen's group.\textsuperscript{25} The latter data also are plotted with the results of this study in figure 1. It is evident that lung volume is not a linear function of height. Figure 2 shows the same data on a double logarithmic scale. The straight lines represent the mean values calculated by Bateman for men of heights ranging from 164 to 186 cm. The same relationship evidently applies almost equally well from about 110 to 205 cm. of height. Data on male subjects reported previously by others are summarized in figure 3. We have calculated the average volumes for each range of height of 5 cm.; all were corrected to BTPS and for the effect of the recumbent position when necessary. Since the study of Aslett's group\textsuperscript{15} included men up to 63 years of age, their data on vital capacity were omitted and only data for total lung volume were used.

It is evident that our data for men of average height coincide with those of previous studies and that the cube of height also applies to lung volumes of men taller than 6 feet (183 cm.).

We have calculated the variation of our measurements and those of Helliesen and co-workers from values estimated from Bateman's prediction formula (see table). The mean values differ by only a few per cent, and the coefficients of variation of 10 to 13 per cent are similar to Bateman's values.

Figure 4 presents our average values for each 5-cm. segment of height, plotted on an arithmetic scale. This permits a comparison with the values predicted by several of the more widely used and recent formulas that predict vital capacity as a linear function of height.\textsuperscript{1,5,10,21} When age was also a variable in the formula, the average age of our subjects, namely 31 years, was used. It is apparent that even the best linear formula predicts values that are too small as height increases above the average and too large in the shorter height range of the

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure4.png}
\caption{Measured vital capacities and various prediction formulas.}
\end{figure}
pediatric age. It should be stated that all these formulas were designed for adults and were not considered as necessarily applying to children.

**Comment**

Of the various measurements of body build, height generally has been found to be the single measurement with which lung volumes can be correlated best. Previous studies describing lung volumes as a linear function of height dealt for the most part with persons of a limited height range; over such limited ranges, the correlation may be satisfactory. However, the correlation is not satisfactory when the height range is extended.

It appears reasonable that a better correlation should exist between lung volumes and the third power of height than with the first power of height, since the body is three-dimensional. This has been pointed out several times in the literature, but its use has not been widely adopted. Although the relationship between lung volumes and the cube of height is similar for a range between 120 and 206 cm., there are data to indicate that equations having the same coefficients or exponent or both may not apply to newborns and infants. Anthropometric studies show that the ratio of actual body volume to the cube of body height in infants is almost twice that in adults, which is a reflection of the relatively large trunk and head of the newborn. Other anatomic studies show that the ventilatory portions of the lung lag behind in development, and the adult ratio of ventilatory to nonventilatory tissue is established at about 3 years. The functional residual capacity of newborns has been determined by Berglund and Karlberg: on the basis of the relationship to metabolic rate, it was considerably smaller than in adults. If the functional residual capacity is equalled 0.5 times the cube of the height (meters), it would be 62.5 ml. in an infant 50 cm. in length. This is less than the value of about 95 ml. that was observed for a 3.5-kg. infant.

The older literature stated that athletes and people indulging in strenuous physical labor tend to have larger vital capacities. However, other studies do not support this concept, while one study indicated that the vital capacity increases after much skin diving. For the 10 tall (193 to 206 cm.) professional athletes in our study, the mean ratio of predicted to measured vital capacity was 0.94, using the same formula as for nonathletes (see table). One well-proportioned, 28-year-old athlete, 200 cm. tall and weighing 105 kg., had a vital capacity of 8.76 liters, which to our knowledge is the largest recorded value in the literature.

**SUMMARY**

Measurements of vital capacity and total lung capacity were made on healthy men of heights up to 206 cm. (81 inches), extending previous measurements on boys and men of average height. In the range between 120 and 206 cm. of height, lung volumes are closely related to the third power of height, as shown by others. The prediction formula of Bateman, relating volume to the cube of height, is applicable over greater ranges of height than are other linear equations in current clinical use for estimating the normal lung volumes from height.

**ACKNOWLEDGMENT:** The authors gratefully acknowledge the assistance of Rita Schmelzer, Henrietta Cranston, Darlene Timmerman, Darlene Smith and Jean Frank.

**RESUMEN**

Se llevaron a cabo las medidas de la capacidad vital y de la capacidad pulmonar total de hombres de estatura hast a 206 cms. (81 pulgadas) además de las medidas de jóvenes y hombres adultos de estatura media. Entre las estaturas de 120 a 206 cms., los volúmenes están en relación estrecha con la tercera potencia de la altura como otros lo han mostrado.

La fórmula para la predicción de Bateman relacionado el volumen al cabo de la altura es aplicable a las estaturas mayores que otras ecuaciones lineales en el uso clínico corriente para valorar los volumenes normales del pulmón de acuerdo con la estatura.

**RESUMÉ**

Des mesures de la capacité vitale et de la capacité respiratoire totale furent faites sur des individus sains dont la taille allait jusqu'à 2 m.06. Il s'agit donc d'une extension des mesures antérieures qui portaient sur des garçons et des hommes de taille moyenne. Dans la limite comprise entre 1m.20 et 2m.06, les volumes respiratoires sont étroitement liés au tiers de la taille, comme d'autres l'ont montré. La normale de Bateman, liant le volume respiratoire au cube de la hauteur, est applicable sur de plus grandes échelles de taille que ne le sont les équations linéaires dans l'emploi clinique courant pour évaluer les volumes respiratoires normaux d'après la taille.

**ZUSAMMENFASSUNG**

Es wurden Messungen der Vitalkapazität und des gesamten Lungenvolumen vorgenommen bei gesunden Männern mit einer Körpergröße bis zu 206 cm in Erweite-
Lungenvolumina der Männer. Beim Vergleich der Größe der Lungen mit der Körpergröße wird festgestellt, dass die Lungenvolumina für die verschiedenen Altersstufen der Männer unterschiedlich sind. Es wird auch darauf hingewiesen, dass die Lungenvolumina von der Körpergröße und der Körperbauart abhängen.

**REFERENCES**


