The Relationship of Several Ventilatory Capacities and Lung Volumes to Age, Height, and Weight

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Most prediction formulae for static and dynamic lung volumes have been derived from multiple or stepwise regression techniques. The majority employ age, height, or weight as "predictors" or "independent variables" and frequently they are assumed to be linearly related to lung volume. The purpose of this study was to evaluate this assumption and to present normal prediction equations for several lung volumes and ventilatory capacities which were derived by a radiographic method.

A study sample of 666 coal miners was selected from 9076 miners who participated in the U.S. Public Health Service's National Study of Coalworkers' Pneumoconiosis. Each participant of the national study had administered to him the Medical Research Council of Great Britain's (MRC) questionnaire[1] and a detailed occupational and smoking history. A medical examination was performed which consisted of posteroanterior and lateral chest radiographs and a test of spirometry. An Ohio 800 waterless hifidelity spirometer was used and all values were corrected to BTPS.[2] Complete details of the methodology can be found elsewhere.[3, 4] The chest films were interpreted for coalworkers' pneumoconiosis using the UICC/Cincinnati classification.[5] Each miner in the study sample was selected on the following basis: 1) That his chest radiograph showed no evidence of coalworkers' pneumoconiosis or any other disease likely to impair ventilatory function, 2) that he was a life-long nonsmoker, and 3) that he did not admit to having any current respiratory symptoms or previous significant chest illness. A further description of the study group as well as prediction equations for forced expired volume in one second (FEV_1), and forced vital capacity (FVC) have been presented elsewhere.[6]

The regression relationship with age, height, and weight was determined for FEV_1, FVC, total lung capacity (TLC), residual volume (RV), (FEV_1/FVC)%, and (RV/TLC)%. TLC was calculated from the posteroanterior and lateral chest films by Barnhard's method.[7] RV was calculated by subtracting the FVC from TLC.

The assumption of a linear relationship was evaluated by comparing equations involving linear, quadratic, and cubic terms. The square of the multiple correlation coefficient (R^2) indicates the proportion of the variation in lung volume attributed to the independent variables in the prediction equation and was used to compare the different regression formulae. The difference in R^2 between two equations was statistically tested by the general linear hypothesis model[8] and all tests of significance were made at the 5% level or probability.

The analysis for each lung volume was performed in four steps. Each successive step was devised so as to show whether the pulmonary indices studied were predicted better from linear than from quadratic, cubic, or cross-product terms of age, height, and weight. Linear equations were calculated in steps 1 and 4 and a stepwise regression procedure was used in steps 2 and 3.[8, 9] In step 1, regression equations were derived to predict FEV_1 and FVC from age and height, TLC from height, and RV, (RV/TLC)%, and (FEV_1/FVC)% from age, i.e. the models most frequently employed at the Appalachian Laboratory for Occupational Respiratory Diseases. During the stepwise analysis of step 2, the linear terms that were described in step 1 were forced to remain in the equations. As significant quadratic, cubic, and cross-product terms of age, height, and weight were added to the linear terms, the increase in R^2 was quantified and the contribution of the higher order terms was evaluated. In step 3, no terms were forced to remain in the equations. A stepwise analysis was performed on all linear, quadratic, cubic, and cross-product terms, and the equations derived were compared to those formulated in steps 1, 2, and 4.

All statistical analyses were performed by the Statistical Analysis System (SAS)[9] available on West Virginia University's IBM 360-75 computer. For each equation, the multiple correlation, R, R^2 and the terms of age, height, and weight involved were recorded.

Descriptive data is presented in Table 1. The sample average and standard deviation are listed for age, height, weight and each pulmonary index.

It was found that the linear terms of age and height predicted FEV_1 and FVC as accurately as the non-linear terms (Table 2). The addition of higher degree terms to the linear variables accounted for significant but not appreciable increases in R^2 (e.g. the R^2 for FEV_1 when predicted from age and height was .444, and only .449 after including the only significant non-linear term, 'age^3 x $weight^{3}$'). Furthermore the addition of weight to age and height did not appreciably increase the R^2 for FEV_1 or FVC Table 3).

Results for FEV_1/FVC%, TLC, RV, and

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Table 1. — Averages and Standard Deviations.		
	Average	Standard Deviation
Age	37.56	12.84
Height	69.31	2.54
Weight	181.66	28.67
FEV1	3.96	0.75
FVC	5.04	0.92
(FEV1/FVC)%	78.83	6.64
TLC	6.88	1.15
RV	1.86	1.03
(RV/TLC)%	26.23	12.42

Table 2. — The Independent Variables†, Multiple Correlation (R), and R^2 Recorded for Equations Developed During the First Three Steps of Analysis‡.

		FEV1	FVC	(FEV1/FVC)%	TLC	RV	(RV/TLC)%
1	Variables in regression equation	A,H	A,H	A	H	A	A
	R	0.666	0.649	0.307	0.456	0.636	0.683
	R^2	0.444	0.421	0.094	0.208	0.405	0.467
2	Variables forced to remain in regression equations	A,H	A,H	A	H	A	A
	Variables added by stepwise procedure	$A^3 \cdot W^3$	$A^3 \cdot W^2$	$H^3, A^3 \cdot W$	$A \cdot W \cdot H^2$	$A^2 \cdot W^2 \cdot H^3$	$A^2 \cdot W^3, A \cdot H$
	R	0.671	0.662	0.388	0.577	0.694	0.710
	R^2	0.449	0.439	0.151	0.333	0.481	0.504
3	All variables added by stepwise procedure	A^2, H^3 $A \cdot W^2$	$H, A^3 \cdot W^2$	$A \cdot H^3$ $A^3 \cdot WH^3$	H^3 $A \cdot W \cdot H^2$	$A^2 \cdot W \cdot H^2$ $A \cdot W^3 \cdot H^3$	$H, A^2 \cdot W$
	R	0.671	0.662	0.383	0.577	0.694	0.708
	R^2	0.449	0.438	0.147	0.334	0.481	0.501

†Independent variables are coded: A = Age, H = Height, and W = Weight
‡All variables listed were significant at the 5% level

RV/TLC% indicated that linear terms predicted these pulmonary indices as accurately as quadratic or cubic terms (e.g. the addition of height to age in predicting $FEV_1/FVC\%$ yielded a R^2 of 0.137, a figure which was similar to 0.151 at step 2 and 0.147 at step 3). The linear terms however were not those described in step 1. The best predictors for $FEV_1/FVC\%$ and TLC were age and height and for RV and RV/TLC% were age and weight. For FEV_1/FVC and TLC, the addition of weight accounted for little improvement in the R^2. The addition of height similarly accounted for little increase in the R^2 when predicting RV and RV/TLC%.

In conclusion, our results indicated that for normal adult coal miners the FEV_1, FVC, $FEV_1/FVC\%$, TLC, RV, and RV/TLC% are not linearly related to age, height or weight, i.e. the addition of quadratic or cubic terms explained a statistically significant amount of the variation in each pulmonary index. However for most practical purposes little information is lost by assuming a linear rather than a quadratic or cubic relationship.

It is possible that other non-linear relationships could improve the prediction of lung volume. However, although data are not presented, fourth and fifth degree terms did not contribute an appreciable amount of information. It is doubtful that polynomials beyond the fifth degree, or non-linear equations involving exponentials or trigonometric functions, would contribute more than the third degree polynomials considered in this study.

A need for adequate prediction equations exists for TLC, RV, and RV/TLC% when TLC is derived radiographically via the Barnhard methodology. It has been shown that the study sample is comparable to Kory's normal population in that predicted values for FEV_1 and FVC from this group compared closely to those from Kory's sample.[6 10] Predicted formulae for normal coal miners are presented in Table 4.

Table 3. — The Independent Variables and R^2 Recorded for Equations Calculated in Step 4.						
Independent Variables in the Prediction Equation	R^2					
	FEV1	FVC	(FEV1/FVC)%	TLC	RV	(RV/TLC)%
age, height, weight	0.448	0.426	0.137 *	0.331	0.078	0.491 †
age, height	0.444	0.421	0.137	0.323	0.432	0.467
age, weight	0.317	0.207	0.100	0.145	0.454	0.487
height, weight	0.256	0.341	0.020 *	0.230	0.078 †	0.095

* Weight not statistically significant at the 5% level
†Height not statistically significant at the 5% level

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Table 4. — Prediction Equations for $(FEV_1/FVC)\%$, TLC, RV, and (RV/TLC)%.		
Equation	Standard Error	R
(FEV1/FVC)% = 124.1565 - .1831 (AGE) - .5548 (HT)	6.1818	0.3702
TLC = -11.1748 + 0.313 (AGE) + .2438 (HT)	0.9487	0.5686
RV = -1.4670 + .0501 (AGE) + .0080 (WT)	0.7635	0.6737
(RV/TLC)% = -9.6891 + .6538 (AGE) + .0625 (WT)	8.9035	0.6982