which results were presented by Dr Laszlo was typical of the advanced disease. In his view it was a disgrace that this diagnosis was not mentioned by four of the laboratories.

Dr Laszlo replied that he found the standard of reporting astonishingly high; possibly his method of presenting the results had not done justice to those who had reported on them.

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Height Standardization of Ventilatory Function

The equation widely used to height-standardize forced expiratory volume (FEV_1) and forced vital capacity (FVC) over the last fifteen years is the multiple regression on age and height,

$$FEV_1 = a_1 + b_1 \times \text{age} + c_1 \times \text{ht} + \text{error}$$

A better alternative is provided by the new regression equation

$$FEV_1/\text{ht}^2 = a_2 + b_2 \times \text{age} + \text{error}$$

which is termed proportional regression, and was validated by Cole (1975).

The coefficients in the new equation come from the regression of FEV_1/ht^2 on age, and it provides just as good a fit to the data as multiple regression. Standardizing for height is particularly easy, since FEV_1/ht^2 does not correlate with height; correction to a standard height H_0 is achieved by multiplying by H_0^2, thus $FEV_1 \times (H_0/\text{ht})^2$ is standardized to height H_0.

Standardization for age from the fitted regression line is the same as for multiple regression, except that the correction is made to FEV_1/ht^2. The age-standardized variable can then be multiplied to a standard height as required.

Besides its analytical advantages, proportional regression is valuable for inferring differences in respiratory health between populations. For example, groups of men from the town of Staveley, Derbyshire, with and without symptoms of breathlessness, provide multiple regression lines differing in intercept, age coefficient and height coefficient. (The difference in age coefficient is to be expected, but differing intercepts and height coefficients are difficult to interpret). The proportional regression lines are:

$$FEV_1/\text{ht}^2 = 1.67 - 0.0131 \text{ age}$$

for men without symptoms ($N = 684$), and

$$FEV_1/\text{ht}^2 = 1.64 - 0.0155 \text{ age}$$

for those with ($N = 175$). Thus the new equation also gives differing slopes for age, but the intercepts are almost identical, showing that the difference between the groups in FEV_1/ht^2 is very small in early life, but increases with increasing age (Fig 1A). The difference in health can be summarized by the hypothetical age at which the two lines predict a zero FEV_1: 127 years for healthy men, but only 106 years for men with breathlessness, a highly significant difference ($P < 0.001$). These ages are the ratio of the intercept and age slope in the equation, with reversed sign.

A second example concerns black and white workers in a New Orleans asbestos cement factory (Rossiter & Weill 1974). They provide proportional regression lines of:

$$FEV_1 = a_1 + b_1 \times \text{age} + c_1 \times \text{ht} + \text{error}$$

for whites ($N = 380$), and

$$FEV_1/\text{ht}^2 = a_2 + b_2 \times \text{age} + \text{error}$$

for blacks: ($N = 443$).

In this case the intercept as well as the slope is obviously smaller, indicating that at all ages blacks have a smaller predicted FEV_1 than whites (Fig 1B). There is no reason to believe that the two groups differ in respiratory health, and blacks are widely held to have genetically smaller lung volumes than whites (Rossiter & Weill 1974). Thus it might be expected that the two regression lines

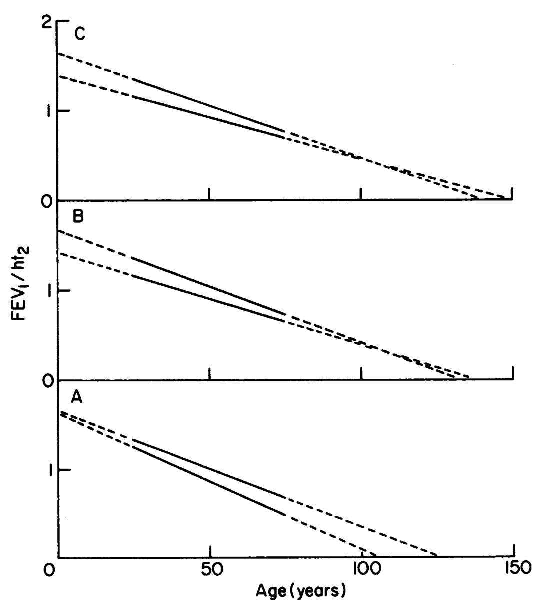

Fig. 1 *Regressions of* FEV_1/ht^2 *on age in:* A, *men with (below) and without breathlessness in Staveley, Derbyshire;* B, *black (below) and white male workers in New Orleans (Rossiter & Weill 1974);* C, *men (above) and women in Tecumseh, Michigan (Higgins & Keller 1973)*

predict a zero FEV_1 at very similar ages, which they do; 133 years for the whites and 138 for the blacks ($P>0.2$). On the hypothesis that this age-to-zero FEV_1, rather than the age slope, is the more appropriate measure of respiratory health, we may conclude that the blacks and whites are very similar in health, whereas the two Staveley groups are obviously different.

A final example, from Tecumseh, Michigan, compares the two sexes (Higgins & Keller 1973). Men ($N=1922$) have a proportional regression line of

$$FEV_1/ht^2 = 1.66 - 0.0118 \text{ age}$$

whereas for women ($N=2092$)

$$FEV_1/ht^2 = 1.39 - 0.0093 \text{ age}$$

with both the intercept and age slope smaller (Fig 1c). Yet here again the ratio of the two, the age-to-zero FEV_1, is very similar in the two groups, 141 and 150 years respectively ($P>0.05$). Thus on the stated hypothesis, the health of the sexes is also similar.

Other sex and ethnic group comparisons described by Cole (1975) also tend to support the hypothesis. Thus the ratio of intercept to age slope can be thought of as a measure of the respiratory health of the population. Furthermore, the intercept alone is a good index of genetic lung size, its values for white males in the four groups in Fig 1 all lying between 1.64 and 1.67, with those for white women and black men appreciably less, around 1.4.

Thus the proportional regression equation is analytically more straightforward than multiple regression, and provides other advantages as well. In addition, everything here referred to the FEV_1 may with equal justification be applied to the FVC. This of course provides a larger age-to-zero FVC, with a larger intercept than the FEV_1 but a similar age slope.

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Dr T J Pedley asked whether the power of two for height had any functional interpretation, since metabolic requirements in a wide range of mammalian species were known to correlate with surface area, or length squared. **Mr Cole** replied that, in an allometric sense, ventilatory function corresponded to the fourth power, rather than the square, of height. The theoretical explanation for this was discussed in some detail by Cole (1975). In reply to Dr J M Patrick, who wondered if the relationships for men and women worked for boys and girls, Mr Cole replied that the growth component in children provided larger correlations between FEV and height than that in adults, so that the corresponding power of height was also greater, about 2.7 rather than 2.

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When is a Lung Function Result Abnormal?

A result may be abnormal on account of technical imperfection in the measurement or of deviation from the chosen reference value. However, a departure from normal may be obscured by variability around the reference value or in the measurement, though the latter can be compensated for by studying groups of subjects. For individuals the detection of what may be a biologically important deviation from normal is often difficult, and requires either more sensitive techniques and reference values or acceptance of a material uncertainty in interpreting the results.

Technical abnormality may be due to the equipment not working properly, an instrument calibration being unsatisfactory or the subject not complying fully with instructions. In addition the recordings obtained during the measurement, also the intermediate and final results, should conform to criteria which can be defined. In the case of single-breath tests including the forced expiratory flow, the transfer factor and the closing volume, the criteria relate to the amplitude, rate and continuity of a respiratory excursion and the absence of undue perturbation, for example, by coughing, cardiogenic oscillations or, in the case of lung compliance, œsophageal contractions. Some criteria are reviewed elsewhere (MRC 1965, National Heart and Lung Institute 1973, Cotes 1975*a*). In the case of progressive submaximal exercise the criteria relate to the intermediate results, including the ways of plotting the linear parts of the relationships of ventilation and cardiac frequency on uptake of oxygen and of minute volume on tidal volume. Some examples are given in Fig 1. Their occurrence should usually lead to the exercise being repeated but the result may often be salvaged by drawing a line through all the points and interpolating to a predetermined value of oxygen uptake and ventilation. Some details are given elsewhere (Cotes 1972). As well as the intermediate values the final result may also be aberrant in relation to other information about the subject. However, at this stage in the processing of results the likelihood of technical error is small; a biological explanation is more probable.