

Reference values and prediction equations for normal lung function in a non-smoking white urban population

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Abstract

Prediction equations for normal lung function have been derived from tests on 179 healthy, non-smoking, white urban dwellers. The subjects, 96 women (height 1.46-1.77 m) and 83 men (height 1.61-1.96 m) aged 18-86 years, underwent measurements of spirometric flow and volume, multi-breath helium dilution lung volumes, and single breath carbon monoxide transfer factor and the single breath nitrogen washout test. Regression analysis using height, age, and weight as independent variables was used to provide predicted values for both sexes. Correlation coefficients were similar to those found in previous studies but normal ranges for spirometric measurements were narrower than in many previous studies, and spirometric flow and volume measurements were higher than those obtained in studies that included cigarette smokers, reflecting our more stringent criteria for selecting subjects and the newer standardised technical methods adopted. Multi-breath helium dilution values for total lung capacity were similar to those found in previous studies but the inspiratory vital capacity was larger and the residual volume reduced. Values for carbon monoxide transfer factor and the single breath nitrogen washout did not differ significantly from existing values. A complete set of lung function reference values and prediction equations for both sexes has been derived from a single population. The exclusion of cigarette smokers and subjects with respiratory symptoms has produced values that should have a greater sensitivity in the detection of mild lung disease.

Normal lung function values and ranges are conventionally calculated according to variables such as age, height, and weight, which contribute independently to predictions of lung function. The prediction equations should be derived from a normal and representative population tested by standardised technical methods and subjected to appropriate statistical analysis.

Many of the older studies still used as reference values fail to meet these criteria. The definition of normal subjects has varied widely and in some has included cigarette smokers and individuals with respiratory sym-

ptoms,¹⁻⁷ whereas in others no definition is given.^{8,9} Some studies have even discarded low values arbitrarily, using minimum spirometric values as selection criteria for normal subjects.^{1,10} Most recent studies have excluded smokers¹¹⁻¹⁷ because the values found even in asymptomatic smokers may deviate from those in non-smokers.

Some published studies have used values for population subgroups defined by age, sex, race, or religion,^{7,18-21} or have produced normal ranges for a limited number of tests only.^{13,14,16}

As a result, many lung function laboratories have been forced to adopt reference values derived from several different lung function studies. In an attempt to overcome the lack of comprehensive data the European Community for Coal and Steel working party published compound prediction equations recommended for all people of European descent.²² These equations are based on data from studies carried out over 30 years, and thus incorporate the inconsistencies that arise from the use of variously defined normal groups. They also include data from smokers, and from studies that were not carried out according to currently recommended technical guidelines.^{22,23} They are not weighted for the numbers included in individual studies, and the normal ranges about the mean predicted values are "best estimates" with little statistical validity. Finally, the decline of lung function with age seen in longitudinal studies has differed significantly from the decline predicted from cross sectional data,²⁴⁻²⁷ suggesting that data from cross sectional studies reflect the population of that time and are valid only for a limited period before population changes render them obsolete. Until long term longitudinal studies are completed cross sectional data should be renewed at intervals. The present study was stimulated by a research requirement for contemporary normal ranges for some lung function values. The opportunity was taken to provide a comprehensive set of lung function prediction equations for both sexes, based on contemporary technical and statistical methods with rigorous selection procedures for normal subjects.

Methods

SUBJECTS

Subjects were defined as normal if they were lifelong non-smokers (not more than one cigarette a day for one year), had no history of respiratory or other serious illnesses, and gave negative replies to a simplified Medical

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Research Council respiratory health questionnaire, which covered current respiratory symptoms, previous medical history, time lost from work, and smoking history.

Subjects were mainly recruited through advertisements placed in the hospital foyer and fracture clinic; some elderly subjects were recruited as a result of advertisements placed in a pensioners' newsletter. Eighteen subjects were actively recruited from among hospital staff and medical students to provide a balance of the extremes of height. Of the 204 subjects who volunteered for the study, 25 were rejected because of a history of smoking (9), cough or dyspnoea mentioned on the questionnaire (8), concomitant non-respiratory disease (3), or failure to meet the volume reproducibility criteria of the lung function tests (5).

Each subject was measured for height by stadiometer (Harpenden) and weighed. Age, sex, and occupational details were recorded.

APPARATUS

Because of a laboratory upgrading, two separate systems were used for measurements of airflow, volumes, and transfer factor. Eighty six subjects were studied with the Gould lung function computer (model CPI 5000 IV) and 93 by a combination of the Morgan lung function transfer test (model C) and the Hewlett Packard Vertek pneumotachograph (model 5000 VR). The comparability of these systems was studied with 15 normal subjects, who were tested on both systems on two different days. Intrasubject variability was evaluated in 15 subjects tested on the Gould unit on two occasions on separate days within one week at the same time of day. The nitrogen washout test used a combined Warren E Collins photo-optical nitrogen ionisation sensor (model 21232) and a Hewlett Packard Vertek pneumotachograph for all subjects.

Before the tests the required manoeuvres were demonstrated by the operator and subjects were encouraged and supervised throughout the performance of tests. All tests were carried out between 0900 and 1800 hours. Calibration checks on all instruments were carried out at least weekly.

MEASUREMENTS

Expiratory flow-volume curve

Expiratory flow-volume tracings were recorded from a computerised dry rolling sealed spirometer (Gould CPI) or pneumotachograph (Vertek) with real time plotting. Values from the first three tests performed with an acceptable technique and maximum effort (forced vital capacity (FVC) within 10% of the highest value) were recorded. The highest value for forced expiratory volume in one second (FEV₁), FVC, peak expiratory flow (PEF), and flow at 50% of forced vital capacity (FEF₅₀) was taken independently from the three curves, back extrapolation being used to identify the starting point.²⁸

Closed circuit multi-breath helium dilution

Gould and Morgan units both use thermal conductivity cells to measure functional

residual capacity (FRC), starting from 8% and 12% helium respectively (in 20.9% oxygen, the balance being nitrogen). Measurements were repeated on each subject with a 15 minute interval until two FRC determinations were within 200 ml of each other; usually two and occasionally three attempts were required. During the rebreathing period two inspiratory vital capacity (IVC) manoeuvres were performed. Tidal volume breathing was recorded throughout the test, which continued for at least seven minutes, and until the helium concentration had remained stable for at least 60 seconds. The residual volume (RV) was derived from the FRC minus expiratory reserve volume and total lung capacity (TLC) from RV plus the higher IVC value. The mean of the results from the two tests was taken.

Carbon monoxide transfer capacity

Carbon monoxide transfer factor (TLCO) was measured by the single breath method²⁹ on both Gould and Morgan systems with a 10 second breath holding time. Carbon monoxide was measured by electrochemical (Gould) or infrared absorption (Morgan) cells with an initial concentration of 0.3% in 20.9% oxygen and 10–14% helium, the balance being nitrogen.

At least two attempts were made and accepted if the IVC fell within 10% of the IVC obtained during the multi-breath helium dilution study. The TLCO from the first two acceptable tests was taken. Alveolar volume was measured simultaneously from the dilution of 10% (Gould) or 14% (Morgan) helium and was used to calculate the transfer factor corrected for volume (TLCO/VA). The mean of two acceptable tests was taken for the TLCO and TLCO/VA.

Single breath nitrogen washout

This was performed as described by Buist and Ross³⁰ after the other tests. Expiratory flow was displayed on an oscilloscope trace to provide visual feedback to assist the subject to maintain flow rates below 0.5 l/s. An IVC within 10% of the IVC recorded during the multi-breath helium dilution test was required for a test to be accepted. Values from two tests meeting these criteria were recorded; closing volume (CV), closing capacity (CC), and slope of phase III were determined from each, mean values being recorded.

Table 1 Age distribution of normal subjects subdivided by sex

Age (y)	Number (%) of	
	men	women
18–29	21 (25)	29 (30)
30–39	16 (19)	11 (11)
40–49	12 (14)	17 (18)
50–59	14 (17)	11 (11)
60–69	11 (13)	17 (18)
> 70	9 (11)	11 (11)
Total	83 (100)	96 (100)
Mean	44.9	44.6
SD	17.4	18.5
Skew	0.35	0.30

Table 2 Range, mean, SD, skew, and kurtosis of lung function variables for men and women

Variable	Range	Mean	SD	Skew	Kurtosis
MEN					
FEV ₁ (l)	2.20– 5.87	3.98	0.90	0.11	-0.54
FVC (l)	2.93– 8.02	5.12	1.05	0.37	0.08
TLC (l)	4.83– 9.72	7.10	1.04	0.11	-0.37
IVC (l)	3.40– 7.90	5.25	0.94	0.46	0.34
FRC (l)	1.99– 5.17	3.51	0.82	0.24	-0.78
RV (l)	0.87– 3.55	1.90	0.54	0.81	0.85
PEF (l/s)	4.41–13.85	10.59	1.77	-0.74	1.00
FEF ₅₀ (l/s)	1.76– 8.15	4.54	1.58	0.41	-0.32
TLco (mmol/min/kPa)	5.18–16.54	10.84	2.52	0.53	1.21
TLco/VA (mmol/min/kPa/l)	1.03– 2.37	1.71	0.32	0.74	1.15
ΔN ₂ % (%/l)	0.35– 2.90	0.84	0.49	1.88	4.50
CV%	3.70–16.54	10.73	2.72	-0.46	0.74
CC%	19.15–64.42	36.69	9.47	1.34	2.04
WOMEN					
FEV ₁ (l)	1.46– 4.61	2.96	0.69	-0.07	-0.71
FVC (l)	1.73– 5.53	3.67	0.77	0.14	-0.25
TLC (l)	3.36– 7.27	5.24	0.70	0.23	0.29
IVC (l)	1.49– 5.57	3.69	0.75	-0.01	0.21
FRC (l)	1.59– 3.73	2.67	0.48	0.10	-0.27
RV (l)	0.72– 2.54	1.55	0.40	0.65	-0.04
PEF (l/s)	3.32–10.55	7.41	1.52	-0.35	0.07
FEF ₅₀ (l/s)	1.30– 6.66	3.86	1.26	0.12	-0.60
TLco (mmol/min/kPa)	5.03–13.93	7.96	1.53	-0.46	0.74
TLco/VA (mmol/min/kPa/l)	1.11– 2.75	1.69	0.29	-0.77	1.83
ΔN ₂ % (%/l)	0.05– 4.50	1.09	0.73	2.17	6.83
CV%	2.25–28.90	13.25	6.59	0.34	-0.65
CC%	18.00–57.59	38.27	9.37	0.26	-0.65

FEV₁—forced expiratory volume in one second; FVC—forced vital capacity; TLC—total lung capacity; IVC—inspiratory vital capacity; FRC—functional residual capacity; RV—residual volume; PEF—peak expiratory flow; FEF₅₀—forced expiratory flow at 50% of forced vital capacity; TLco—carbon monoxide transfer factor; VA—alveolar volume; N₂—nitrogen; CV—closing volume; CC—closing capacity.

Closing volume was taken as the point of terminal increase of nitrogen concentration along the alveolar plateau and was expressed as a proportion of the vital capacity (CV/VC%). In cases where no clear point of terminal increase in nitrogen concentration (phase IV) could be identified closing volume was recorded

as 0%. Closing capacity (closing volume plus residual volume from the multi-breath helium dilution) was expressed as a proportion of TLC. The slope of phase III was measured as the percentage increase in nitrogen concentration per litre of expired gas after the first 750 ml had been discarded (ΔN₂%/l). The

Table 3 Regression coefficients and constants for prediction equations

Variable	Coefficient term					
	Height (m)	Age (y)	Weight (kg)	Constant	SD	R ²
MEN						
FEV ₁ (l)	3.961	-0.033	—	-1.558	0.51	0.68
FVC (l)	6.628	-0.028	—	-5.377	0.64	0.63
FEV/FVC%	-21.476	-0.242	—	126.252	6.88	0.25
PEF (l/s)	5.317	-0.062	—	3.884	1.24	0.52
FEF ₅₀ (l/s)	—	-0.044	—	6.456	1.41	0.22
TLC (l)	7.956	—	—	-6.948	0.77	0.48
IVC (l)	6.791	-0.021	—	-5.824	0.58	0.63
FRC (l)	7.502	0.009	-0.033	-7.608	0.68	0.33
RV (l)	3.380	0.020	-0.014	-3.927	0.43	0.37
RV/TLC%	—	0.246	—	16.108	4.58	0.50
TLco	14.005	-0.074	—	-10.803	1.89	0.52
TLco/VA	—	-0.009	—	2.086	0.34	0.18
ΔN ₂ % (%/l)	—	0.015	—	0.207	0.42	0.29
CV (%)	—	0.250	—	3.362	5.02	0.50
CC (%)	—	0.387	—	20.488	5.59	0.66
WOMEN						
FEV ₁ (l)	3.321	-0.025	—	-1.394	0.39	0.67
FVC (l)	4.321	-0.023	—	-2.379	0.49	0.60
FEV/FVC%	—	-0.172	—	88.134	6.74	0.18
PEF (l/s)	4.087	-0.050	—	2.945	1.10	0.49
FEF ₅₀ (l/s)	—	-0.038	—	5.556	1.05	0.31
TLC (l)	7.107	—	—	-6.435	0.53	0.43
IVC (l)	4.025	-0.022	—	-1.943	0.51	0.55
FRC (l)	5.867	0.009	-0.022	-5.972	0.35	0.48
RV (l)	2.548	0.017	—	-3.387	0.29	0.49
RV/TLC%	—	0.346	—	14.265	5.52	0.57
TLco	7.391	-0.037	—	-2.516	1.19	0.41
TLco/VA	—	-0.006	—	1.937	0.27	0.12
ΔN ₂ % (%/l)	—	0.008	—	0.753	0.72	0.04
CV (%)	—	0.248	—	2.599	4.83	0.47
CC (%)	—	0.420	—	19.713	5.55	0.65

For abbreviations see table 2.

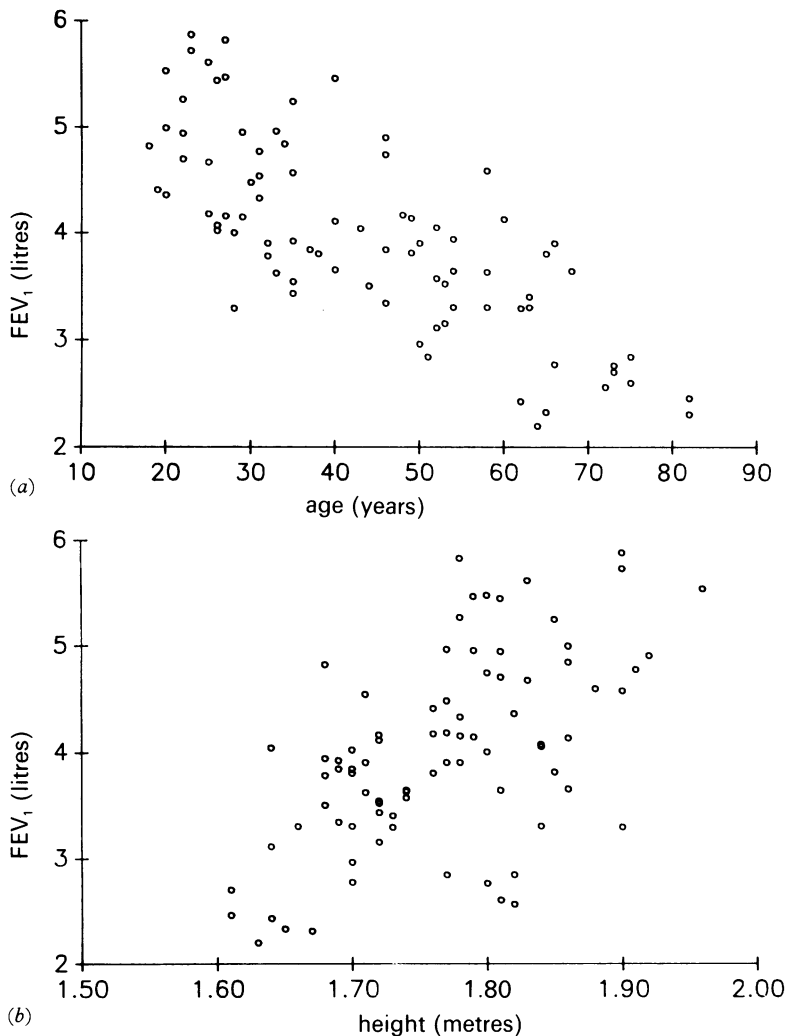


Figure 1 Scattergram of measured forced expiratory volume in one second (FEV_1) against (a) age and (b) height in the 83 male subjects. The equations, derived by linear regression, are: (a) $FEV_1 = -0.04 \text{ age} + 5.73$ ($r = -0.76$); (b) $FEV_1 = 6.59 \text{ height} - 7.65$ ($r = 0.58$).

measurement was made from a visually determined "best fit" line drawn through the remaining alveolar phase by one observer.

ANALYSIS

All data were transferred to the University of London computer (Amdahl 5890) and analysed with the Statistical Package for Social Sciences (SPSS Inc, Chicago). Transcription error checks were carried out at each stage of data input. Scatterplots of lung function variables against height, weight, and age were examined initially for each sex, and outlying values investigated for transcription or methodological error. The distribution of these independently contributing variables was examined for skew and kurtosis to determine whether transformations were necessary before regression analysis could be performed.

Table 4 Alternative expressions for spirometric results in men over 25 years

Variable	Height (m)	Age (y)	Constant	SD	R^2
FEV_1 (l)	3.768	-0.033	-1.252	0.51	0.69
FVC (l)	5.816	-0.028	-3.931	0.64	0.63
PEF (l/s)	5.699	-0.063	3.309	1.24	0.52
FEV_1/FVC (%)	—	-0.207	86.855	7.02	0.21

For abbreviations see table 2.

Multiregression analysis by forward, backward, and stepwise methods was used to produce prediction equations for each lung function variable with the independent variables and a constant. Predicted values were then plotted against the original values to produce correlation coefficients, coefficients squared, and standard deviations from the predicted means. The criterion of significance for including a variable in the regression equation was $p < 0.05$. The linearity of decline of spirometric variables with age was tested by comparing the correlation of regression equations derived for age subsets and for the whole group. Plots of residual values against predicted values were made. When indicated, square root, squared, and log transformations were tested for better fits with the regression line.

Results

The variability between measurements made on the two lung function machines and on the Gould machine on two occasions are given in appendix tables A and B. The differences between the mean values obtained on the two systems were small and in general similar to the difference between repeat measurements on the Gould system. Data obtained with the two systems were therefore combined for the remainder of the calculations.

Of the 179 subjects who completed the spirometric, helium dilution, and gas transfer measurements, 96 were women (mean height 1.64 (range 1.46–1.77) m, mean weight 63.9 (range 42–98) kg) and 83 were men (mean height 1.77 (range 1.61–1.96) m, mean weight 75.2 (range 52.8–108.4) kg). A positive skew towards higher weight was seen in the female group but other variables had a normal distribution. The age distribution is detailed in table 1. Eighteen subjects were unable to complete the single breath nitrogen washout test satisfactorily, and in a further 17 phase IV could not be identified. Thus satisfactory data for this test were obtained from 144 subjects (76 women and 68 men). Mean values, with the range and standard deviation with skew and kurtosis values for each lung function variable, are shown in table 2. The regression coefficients and constants for the prediction equations of lung function are described in table 3. Figure 1 gives an example showing how FEV_1 varied with height and age.

The linearity of decline of spirometric variables with age, as assessed by correlation coefficients and residuals, did not improve when ages of 25 or 30 rather than 18 years were taken as the starting points. Prediction equations derived from this group of subjects appear therefore to be valid from age 18. Other studies have suggested that decline in spirometric lung function in men does not begin until the age of 25 or more²⁴⁻²⁷; we have therefore included regression equations for men from 25 years onwards (table 4).

Squared, square root, and log transformations were explored to improve the fit and reduce the scatter for the slope of the phase III of the nitrogen washout, which has a heteroscedastic distribution (fig 2). The best fit log transformation reduced the coefficient of skew from 1.526 untransformed to 0.032 but failed to

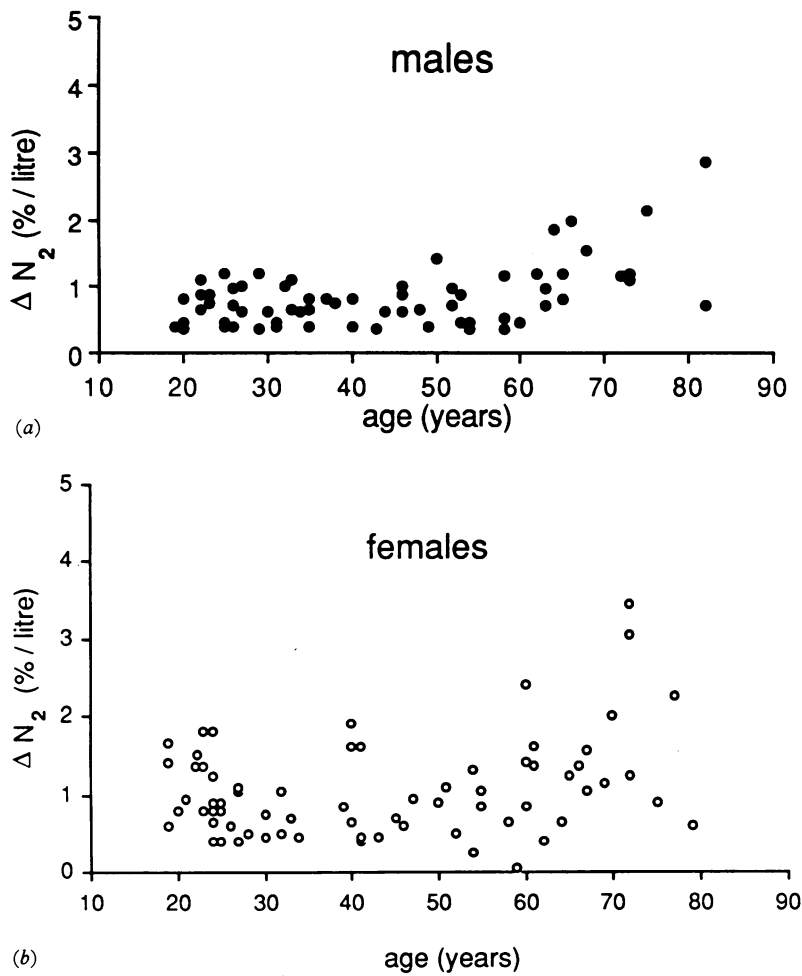


Figure 2 Scattergrams of slope of phase III of nitrogen washout against age for (a) men and (b) women, illustrating the increased scatter of values in older subjects. Prediction equations, based on linear regression, for the full age range are given in table 3. For subjects of both sexes under 60 years narrower normal ranges are obtained by using mean and SD (see text).

improve either the correlation coefficient or the standard deviation from the predicted mean. Predicted values are therefore expressed in the simpler untransformed manner used for all other lung function variables. An alternative approach³¹ has been to divide the data according to the point of transformation from homoscedasticity to heteroscedasticity, which is age related, and to provide normal ranges up to this age (60 years in both sexes). This gives narrower normal ranges for the under 60s (derived simply from the mean and SD) and may have more value for detecting early abnormalities in these age groups. Results calculated for the slope of phase III in this way are:

Men (mean 0.686% (SD 0.285)/l): upper limit of normal (mean + 1.645 SD) 1.155 %/l

Women (mean 1.039% (SD 0.616)/l): upper limit of normal 2.052 %/l.

The prediction equations for closing volume and closing capacity in table 3 exclude subjects who did not show a phase IV on the nitrogen washout (closing volume 0%). As this might create a falsely high normal range, we give alternative prediction equations that include subjects with zero values:

Men CV(%) = 0.79 × age (years) + 0.576

Women CV(%) = 0.153 × age (years) + 4.741.

Discussion

This study presents the lung function data and prediction equations derived from 179 healthy, non-smoking, white men and women who have lived all or most of their lives in an urban environment. The subjects represent a wide range of heights and ages and were drawn from various occupational and social classes. The prediction equations produced from these data provide normal values and ranges for spirometric variables, static lung volumes, transfer factor, and results of small airway tests. Such a comprehensive range of values has not previously been available for both sexes from one population group.

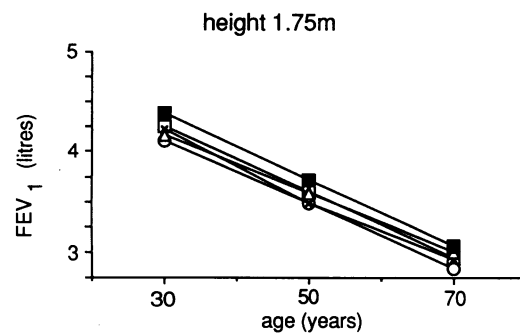
We have used age, height, and weight as predictors of lung function values because we found that they contribute independently to the prediction equations and comparison with existing reference values is facilitated. Multiple and exponential mathematical transformations of variables have not been shown to improve the coefficients of correlation between predicted and measured values of equations consistently^{11 14 32 33} and they add to the complexity of the calculations. The correlation coefficients derived from our data are similar to those from accepted reference studies with the exception of PEF equations, which have higher values than existing data.

The prediction equations for FEV₁ and FVC differ from those from earlier studies^{2 7 18 22 32 34 35} in that they produce higher values for a given age and height for both sexes. An example is shown in figure 3. There are several possible reasons. Firstly, the selection of normal subjects for this study was rigorous and excluded current cigarette smokers, and ex-smokers, who were often included in previous studies. In several studies a statistical difference between non-smokers and symptomless smokers or ex-smokers has been found.^{5 36 37} Combining results from smokers and non-smokers is likely to produce a lower mean value than that obtained for non-smokers alone. Secondly, prediction equations produced 20 or 30 years ago may reflect population characteristics not found in the contemporary population. Such an observation has been noted for spirometric variables^{24 25} and may account for the discrepancies between longitudinal and cross sectional studies. Thirdly, the data may be influenced by the choice of value, from the several produced by the measurements, for each lung function variable. Many previous studies have averaged the two best values for any variable or have taken FEV₁ and FVC readings from the same manoeuvre. The current guidelines of the American Thoracic Society²³ and the European Community for Coal and Steel working parties²² recommend that the single best values be taken independently from at least three technically acceptable maximum efforts. These standards may yield slightly higher results than those used in some earlier tests.

Although the spirometric values presented are higher than those in many earlier series they show substantial concordance with those of the three most recently published series from

Figure 3 Examples of comparisons of predicted values from the present study and some previous studies. Graph shows forced expiratory volume in one second (FEV_1) in men against height and age.

■ This study; □ Cotes *et al*²; ○ Morris *et al*¹⁸; △ European Community for Coal and Steel working party²²; × Kory *et al*.³²



Europe and North America.¹²⁻¹⁴ These studies also excluded cigarette smokers and followed technical guidelines similar to those used in our study. The general agreement between contemporary studies and disagreement with earlier series suggests that selection criteria and newer techniques have produced reference values that should supersede those in current use. Peak expiratory flow values derived from our data predict higher values for younger subjects of both sexes but show a decline with increasing age towards levels similar to those seen in earlier studies.

At higher flows the variability of the pneumotachograph was greater than that of the dry rolling seal spirometer, and this may have contributed to some of the higher values. Any such effect could only be minor, however, because on average the spirometer gave marginally higher flow values than the pneumotachograph (appendix tables A and B).

Our prediction equations for static lung volumes in women produce values very similar to those of other series.^{5,7,38} The corresponding values in men, however, differ from those of previous studies, which have included cigarette smokers. The range of TLC values are similar to those obtained in most series^{22,39,40} but our predicted values for VC in men are larger and those for RV are smaller.^{33,38-40} As a result the RV/TLC ratio also falls. The difference in RV is as much as 20% in younger, shorter subjects and falls towards parity in the tall and the elderly. An increase in RV is now recognised as an early feature of smoking related lung disease⁴¹ and this may have influenced the results of previous studies in men, where smoking was more prevalent than among women classified as normal. The exclusion of smokers may account for our findings.

Prediction equations for carbon monoxide transfer factor yield values similar to those of other series for men, but are at the lower end of the range for women.

Normal values for the small airways tests of FEF_{50} , closing capacity, closing volume, and $\Delta N_2\%/l$ have also been produced. The FEF_{50} is considered by many to be a sensitive test of small airways obstruction⁴²⁻⁴⁵ but its clinical use has been hampered by widely differing normal values from different series²² and wide ranges about the mean values.^{5,46} Our values are similar in magnitude to those obtained previously, though the values for women have a smaller variation about the mean, which should improve their usefulness. R values as low as 0.47 ($R^2 = 0.22$), however, exist for FEF_{50}

(table 3), which implies that only 22% of the variance of the observed values is accounted for by age. Similar low R values have been found by previous workers,^{31,46} and they imply that other independent variables, not yet identified, should be included in the prediction equations.

The correlation coefficients for the $\Delta N_2\%/l$ are even lower, only age having a significant, though weak, effect on the value. This prediction is further complicated by a strongly positive skew in the distribution of measured values, due to wider scatter in older subjects (fig 2). Such heteroscedascity reduces the value of regression analysis, which provides normal ranges that are too wide at the lower values and too narrow at higher values. This reduces the sensitivity of the test (which has recently been shown to help to predict the decline of FEV_1 in cigarette smokers⁴⁷). An alternative approach (see "Results") is to provide a fixed normal range based on mean values and standard deviations up to the age of 60, as up to this age $\Delta N_2\%/l$ is effectively independent of age (fig 2).

Values of closing volume and closing capacity are similar to those found in previous studies but are derived from a larger British series than has previously been available. For reasons given below, we have chosen a one sided 95% normal range for these values and the $\Delta N_2\%/l$.

The ability of predicted values to discriminate between normal and abnormal function depends on how normal ranges for each variable are defined. This subject has been extensively debated⁴⁸⁻⁵⁰ and the use of percentage predicted ranges has been universally condemned. They nevertheless remain in use because of ease of calculation and familiarity. The homoscedastic distribution of almost all normal values makes the use of the standard deviation from the mean a much more appropriate expression of the normal range. For variables that may be abnormal in either direction—for example, TLC—a two sided 95% range (± 1.96 SD) should be used, whereas for those variables where only a low value (for example, FEV_1) or a high value (for example, $\Delta N_2\%/l$) is of significance, a one sided 95% range (either - or + 1.645 SD) is appropriate. This approach has a sound observational and statistical basis and provides a single normal range that can be applied to the predicted value for any individual.

The data presented are derived from healthy non-smoking subjects and provide predicted normal values and ranges for such a population group. These values are intended to be used in a clinical setting to assist in early diagnosis and assessment of functional impairment of lung disease. The exclusion of cigarette smokers and individuals with respiratory symptoms improves the sensitivity of applying derived normal values to patients with suspected respiratory disease.

Appendix

Table A Comparison of means, standard deviations (SD), and coefficients of variation (CV%) for lung function variables tested in 15 normal subjects on (a) both the Vertek/PK Morgan (PKM) combination and the Gould lung function computer (Gould 1) and (b) the Gould on two separate occasions (Gould 1, Gould 2)

	Mean	SD	CV%
FEV ₁ (l)			
Vertek	3.77	0.86	22.7
Gould 1	3.72	0.94	25.1
Gould 2	3.72	0.95	25.5
FVC (l)			
Vertek	4.62	1.00	21.6
Gould 1	4.57	1.05	23.1
Gould 2	4.55	1.12	24.6
PEF (l/s)			
Vertek	9.23	1.94	21.0
Gould 1	9.37	2.68	28.6
Gould 2	9.71	2.23	23.0
FRC (l)			
PKM	3.36	0.91	27.1
Gould 1	3.51	0.67	19.2
Gould 2	3.48	0.74	21.2
TLC (l)			
PKM	6.40	1.33	20.7
Gould 1	6.44	1.14	17.8
Gould 2	6.47	1.33	20.6
TLco (mmol/min/kPa)			
PKM	10.01	2.30	23.0
Gould 1	9.57	1.98	20.7
Gould 2	9.77	2.33	23.8

FEV₁—forced expiratory volume in one second; FVC—forced vital capacity; PEF—peak expiratory flow; FRC—functional residual capacity; TLC—total lung capacity; TLco—carbon monoxide transfer factor.

- Leiner GC, Abramowitz S, Small MJ, Stenby VB, Lewis WA. Expiratory peak flow rate. *Am Rev Respir Dis* 1963;88:644–51.
- Cotes JE, Rossiter CE, Higgins ITT, Gilson JC. Average normal values for the forced expiratory volume in white caucasian males. *BMJ* 1966;i:1016–9.
- Milne JS, Williamson J. Respiratory function tests in older people. *Clin Sci* 1973;42:371–81.
- Schmidt CDu W, Dickman ML, Gardner RM, Brough FK. Spirometric standards for healthy elderly men and women. *Am Rev Respir Dis* 1973;108:933–9.
- Black LF, Offord K, Hyatt RE. Variability in the maximal expiratory flow volume curve in asymptomatic smokers and non-smokers. *Am Rev Respir Dis* 1974;110:282–92.
- Schoenberg JB, Beck GJ, Bouhuys A. Growth and decay of pulmonary function in healthy blacks and whites. *Respir Physiol* 1978;33:367–93.
- Hall AM, Heywood C, Cotes JE. Lung function in healthy British women. *Thorax* 1979;34:359–65.
- Motley HL. The use of pulmonary function tests for disability approval: including evaluation standards in chronic pulmonary disease. *Dis Chest* 1953;24:378–89.
- Cherniack RM, Raber MB. Normal values for ventilatory function using an automated wedge spirometer. *Am Rev Respir Dis* 1972;106:38–46.
- Ferris BG, Anderson DO, Zickmantel R. Prediction values for screening tests of pulmonary function. *Am Rev Respir Dis* 1965;91:252–61.
- Dockery DW, Ware JH, Ferris BG Jr, et al. Distribution of forced expiratory volume in one second and forced vital capacity in healthy white, adult never-smokers in six U.S. cities. *Am Rev Respir Dis* 1985;131:511–20.
- Miller A, Thornton JC, Warshaw R, Bernstein J, Selikoff IJ, Teirstein AS. Mean and instantaneous expiratory flows, FVC and FEV₁ prediction equations from a probability sample of Michigan, a large industrial state. *Clin Respir Physiol* 1986;22:589–97.
- Paoletti P, Pistelli G, Fazzi P, et al. Reference values for vital capacity and flow-volume curves from a general population study. *Bull Eur Physiopathol Respir* 1986;22:451–9.
- Roca J, Sanchis J, Agusti-Vidal A, et al. Spirometric reference values from a Mediterranean population. *Bull Eur Physiopathol Respir* 1986;22:217–24.
- Ayub M, Zaidi SH, Burki NK. Spirometry and flow-volume curves in healthy normal Pakistanis. *Br J Dis Chest* 1987; 81:35–44.
- Withers RT, Bourdon PC, Crockett A. Lung volume

Table B Analysis of results of paired tests: means, standard deviations (SD), t and p values, correlation coefficients (r), and coefficients of variation (CV%) for PKM|Vertek-Gould 1; PKM|Vertek-Gould 2, and Gould 1-Gould 2

Pairs	Mean	SD	t	p	r	CV%*
FEV ₁ (l)						
Vertek-Gould 1	0.05	0.21	0.93	0.37	0.98	5.6
Vertek-Gould 2	0.05	0.21	0.98	0.34	0.98	5.5
Gould 1-Gould 2	0.00	0.12	0.04	0.97	0.99	3.2
FVC (l)						
Vertek-Gould 1	0.05	0.26	0.76	0.46	0.97	5.7
Vertek-Gould 2	0.07	0.32	0.89	0.39	0.96	6.9
Gould 1-Gould 2	0.02	0.15	0.56	0.58	0.99	3.3
PEF (l/s)						
Vertek-Gould 1	-0.14	1.58	-0.34	0.74	0.81	17.0
Vertek-Gould 2	-0.48	0.92	-2.04	0.06	0.91	9.9
Gould 1-Gould 2	-0.35	1.09	-1.23	0.24	0.92	11.4
FRC (l)						
PKM-Gould 1	-0.15	0.53	-1.12	0.28	0.82	15.3
PKM-Gould 2	-0.12	0.33	-1.35	0.20	0.94	9.8
Gould 1-Gould 2	0.04	0.36	0.38	0.71	0.88	10.3
TLC (l)						
PKM-Gould 1	-0.04	0.56	-0.27	0.79	0.91	8.6
PKM-Gould 2	-0.07	0.31	-0.86	0.40	0.97	4.8
Gould 1-Gould 2	-0.03	0.45	-0.25	0.81	0.95	6.9
TLco (mmol/min/kPa)						
PKM-Gould 1	0.44	0.87	1.88	0.82	0.93	6.5
PKM-Gould 2	0.24	0.64	1.41	0.18	0.96	6.5
Gould 1-Gould 2	-0.20	0.59	-1.24	0.24	0.98	6.1

*CV% = (SD of differences mean value) of the two systems compared. Abbreviations as in table A.

- standards for healthy lifetime non-smokers. *Chest* 1988; **93**:91-7.
- 17 Nunn AJ, Gregg I. New regression equations for predicting peak respiratory flow in adults. *BMJ* 1989; **298**:1068-70.
 - 18 Morris JF, Koski A, Johnson LC. Spirometric standards for healthy non-smoking adults. *Am Rev Respir Dis* 1971; **103**:57-67.
 - 19 Crapo RO, Morris AH, Gardner RM. Reference spirometric values using techniques and equipment that meet ATS recommendations. *Am Rev Respir Dis* 1981; **123**:659-64.
 - 20 Burr ML, Phillips KM, Hurst DN. Lung function in the elderly. *Thorax* 1985; **40**:54-9.
 - 21 Fowler RW, Pluck RA, Hetzel MR. Maximal expiratory flow volume curves in Londoners aged 60 years and over. *Thorax* 1987; **42**:173-82.
 - 22 Quanjer Ph H, ed. Standardised lung function testing report of the European Community for Coal and Steel working party. *Bull Eur Physiopathol Respir* 1983; **19**:suppl 5.
 - 23 American Thoracic Society. Standardisation of Spirometry. *Am Rev Respir Dis* 1987; **136**:1285-98.
 - 24 Glindmeyer HW, Diem JE, Jones RN, Weill H. Non comparability of longitudinally and cross sectionally determined annual change in spirometry. *Am Rev Respir Dis* 1982; **125**:544-8.
 - 25 Knudson RJ, Lebowitz MD, Holberg CJ, Burrows B. Changes in the normal maximal expiratory flow-volume curve with growth and aging. *Am Rev Respir Dis* 1983; **127**:725-34.
 - 26 Burrows B, Lebowitz MD, Camilli AE, Knudson RJ. Longitudinal changes in forced expiratory volume in one second in adults. *Am Rev Respir Dis* 1986; **133**:974-80.
 - 27 Tager IB, Segal MR, Speizer FE, Weiss ST. The natural history of forced expiratory volumes. *Am Rev Respir Dis* 1988; **138**:837-49.
 - 28 Ferris BG. Epidemiology standardisation project. *Am Rev Respir Dis* 1978; **118**:55-88.
 - 29 Ogilvie CM, Forster RE, Blakemore WS, et al. A standardised breath holding technique for the clinical measurement of the diffusing capacity of the lung for carbon monoxide. *J Clin Invest* 1957; **36**:1-17.
 - 30 Buist AS, Ross BB. Predicted values for closing volumes using a modified single breath nitrogen test. *Am Rev Respir Dis* 1973; **107**:744-52.
 - 31 Buist AS, Ross BB. Quantitative analysis of the alveolar plateau in the early diagnosis of early airways obstruction. *Am Rev Respir Dis* 1973; **108**:1078-87.
 - 32 Berglund E, Birath G, Bjure J, et al. Spirometric studies in normal subjects. I. Forced expirogram in subjects between 7 and 70 years of age. *Acta Med Scand* 1963; **173**:185-92.
 - 33 Knudson RJ, Slatin RC, Lebowitz MD, Burrows B. The maximal expiratory flow volume curve. Normal standards, variability and effects of age. *Am Rev Respir Dis* 1976; **113**:587-600.
 - 34 Kory RC, Callahan R, Boren HG, Syner JC. The Veterans Administration-Army cooperative study of pulmonary function: I. Clinical spirometry in normal men. *Am J Med* 1961; **30**:243-58.
 - 35 Boren HG, Kory RC, Syner JC. The Veterans Administration-Army cooperative study of pulmonary function. II. The lung volume and its subdivisions in normal man. *Am J Med* 1966; **41**:96-114.
 - 36 Miller A, Thornton JC, Warshaw R, et al. Single breath diffusing capacity in a representative sample of the population of Michigan, a large industrial state. *Am Rev Respir Dis* 1983; **127**:270-7.
 - 37 Gregg I, Nunn AJ. Peak expiratory flow in symptomless elderly smokers and ex-smokers. *BMJ* 1989; **298**:1071-2.
 - 38 Goldman HI, Becklake MR. Respiratory function tests. Normal values at median altitudes and the prediction of normal results. *Am Rev Tuberc* 1959; **79**:457-67.
 - 39 Needham CD, Rogan MC, McDonald I. Normal standards for lung volumes, intrapulmonary gas mixing, and maximum breathing capacity. *Thorax* 1954; **9**:313-25.
 - 40 Grimby G, Soderholm B. Spirometric studies in normal subjects. III. Static lung volumes and maximum voluntary ventilation in adults with a note on physical fitness. *Acta Med Scand* 1963; **173**:199-206.
 - 41 Blackburn H, Brozek J, Taylor HL. Lung volume in smokers and non-smokers. *Ann Intern Med* 1959; **51**:68-77.
 - 42 McFadden ER, Linden DA. A reduction in maximum mid-expiratory flow rate. *Am J Med* 1972; **52**:725-37.
 - 43 Berend N, Woolcock AJ, Marlin GE. Correlation between the function and structure of the lung in smokers. *Am Rev Respir Dis* 1979; **119**:695-705.
 - 44 Adams L, Lonsdale D, Robinson M, Rawbone R, Guz A. Respiratory impairment induced by smoking in children in secondary schools. *BMJ* 1984; **288**:891-5.
 - 45 Wright JL, Lawson LM, Paré PD, et al. The detection of small airways disease. *Am Rev Respir Dis* 1984; **129**:989-94.
 - 46 Bass H. The flow volume loop: normal standards and abnormalities in chronic obstructive pulmonary disease. *Chest* 1973; **63**:171-6.
 - 47 Oloffson J, Bake B, Svardsudd K, Skoogh BE. The single breath N₂ test predicts the rate of decline in FEV₁. *Eur J Respir Dis* 1986; **69**:46-56.
 - 48 Sobol BJ, Weinheimer B. Assessment of ventilatory abnormality in the asymptomatic subject: an exercise in futility. *Thorax* 1966; **21**:445-9.
 - 49 Sobol BJ. The early detection of airway obstruction: another perspective. *Am J Med* 1976; **60**:619-24.
 - 50 Miller MR, Pincock AC. Predicted values: how should we use them? *Thorax* 1988; **43**:265-7.