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Prediction equations for normal and low lung function from the Health Survey for England

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Prediction equations for normal and low lung function from the Health Survey for England. E. Falaschetti, J. Laiho, P. Primatesta, S. Purdon. ©ERS Journals Ltd 2004.

ABSTRACT: The aim of this study was to derive new spirometric reference equations for the English population, using the 1995/1996 Health Survey for England, a large nationally representative cross-sectional study.

The measurements used were the forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) of a sample of 6,053 "healthy" (nonsmokers with no reported diagnosis of asthma or respiratory symptoms) White people aged $\geqslant$16 yrs. Multiple regression analysis, with age and height as predictors, was carried out to estimate prediction equations for mean FEV1, FVC and FEV1/FVC, separately for males and females. A method based on smoothing multiple estimates of the fifth percentiles of residuals was used to derive prediction equations for the lower limit of normal lung function.

The new equations fit the current English adult population considerably better than the European Coal and Steel Community equations, and the proportions of people with "low" (below the fifth percentile) lung function are closer to those expected throughout the whole adult age range (16 to >75 yrs). For the age ranges the studies share in common, the new equations give estimates close to those derived from other nonlinear equations in recent studies.

It is, therefore, suggested that these newly developed prediction equations be used for the White English population in both epidemiological studies and clinical practice.

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Reference values, predicted for normal healthy nonsmokers, are generally used in epidemiological work as well as in clinical surveillance to determine low lung function and assess the effect of environmental exposure. A number of sets of prediction equations are currently available for different populations, with those most widely used based on relatively old studies [1–4].

In 1995 and 1996, the general population Health Survey for England (HSE) had a focus on respiratory disease, and the lung function of respondents was measured. Use of European Coal and Steel Community (ECSC) reference values [4] for analysis in the published reports showed that these values were not predictive of normal lung function for the English population [5]. This poor fit for the ECSC reference values prompted the present study, to derive a new set of reference values based on the HSE 1995 and 1996 combined datasets. These newly derived reference values are presented here and compared with the ECSC and other recent reference values.

Methods

The design of the HSE, an annual nationwide household survey of the English population, has been described in detail elsewhere [6]. Briefly, members of a stratified random sample, sociodemographically representative of the English population, were invited to participate in 1995 and 1996. The mean response rate was >75% in both years, but slightly lower than average amongst males and in inner cities. Data on each respondent were collected during two visits, with identical methods used in 1995 and 1996: an interviewer's visit, during which a questionnaire was administered and height and weight measured, followed by a nurse's visit, during which lung function was measured (amongst other investigations). Smoking habits and any respiratory symptoms were recorded in the questionnaire.

Lung function was measured using the Vitalograph Escort Spirometer (Vitalograph, Buckingham, UK), a portable device. A standardised protocol was used and all nurses who took the measurements received identical training and were subjected to repeated briefings during the study period. Before starting any measurements within a household, the spirometer was always calibrated using a 1-L calibration syringe. The nurse then demonstrated the test procedure to the respondents within the household. While in a standing position (unless chairbound), respondents were required to perform a forced inspiration followed by an expiration with maximal effort, without excitation or bending forward. A test was considered technically acceptable if none of the following occurred: an unsatisfactory start of expiration, breath-holding, an obstructed mouthpiece, or the lips not being properly sealed around the mouthpiece. Five consecutive readings were taken, and forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) recorded using the best value from any of the acceptable measurements. Those subjects who gave only unsatisfactory tests were excluded from the analysis. The American Thoracic Society (ATS) acceptability and reproducibility criteria [7] were not applied in this population sample. However, for the purpose of the present study, subjects who did not meet the reproducibility criteria were excluded as individuals with asthma often have problems with reproducibility criteria [8].

The analysis was restricted to White respondents aged ≥16 yrs, since lung function values for non-Whites and younger children are known to differ systematically from those in the White older group. Only "healthy" subjects were used in the derivation of prediction equations. The "healthy" group was defined, according to ATS recommendations, as nonsmokers (both exsmokers and current smokers excluded) with no reported diagnosis of asthma or respiratory symptoms (wheeze in the last 12 months; cough/phlegm for ≥3 months·yr^{-1}; shortness of breath at night, when walking with peers on level ground, when hurrying on level ground or when walking up a slight hill; or on asthma medication in the last 12 months) (table 1).

Statistical analysis

The analytical approach taken was largely that of Brändli *et al.* [1] in their study of lung function in the Swiss population. Multiple regression analysis was carried out to estimate prediction equations for mean FEV1, FVC and FEV1/FVC. The analysis was performed separately for males and females. Equations for the fifth percentiles were then estimated from the residuals of the models for the mean using the approach described by Healy *et al.* [9]. A paired t-test was used to test the differences between predicted lung function from different equations.

Table 1. – Reference sample selection criteria and characteristics of the study sample

	Males	Females
Participants (White) interviewed n		
Total	13883	16646
Less invalid spirometry data	11854	13554
Less ever smokers	4643	6845
Less nonhealthy subjects	3107	4195
Less irreproducible data	2497	3556
Age in years n		
16–24	424	507
25–34	620	802
35–44	583	750
45–54	376	593
55–64	260	416
65–74	157	329
75–84	51	134
≥85	8	25
Age last birthday yrs	40±15.7	43±17.0
Height cm	176±6.8	162±6.4
FEV1 L	4.1±0.81	2.9±0.65
FVC L	5.0±0.94	3.5±0.74
FEV1/FVC	0.82±0.072	0.83±0.071

Data are presented as absolute values or mean±SEM. FEV1: forced expiratory volume in one second; FVC: forced vital capacity.

Prediction equation for the mean. The relationship between lung function, age and height can be assumed to take one of two forms, additive or multiplicative [1–4]. The multiplicative model has been shown elsewhere to better describe the dependency of lung function on age and height [10, 11], and, overall, gave a better fit to the HSE data. This model assumes:

$$\mathrm{LF} = \mathrm{H}^c f(\mathrm{A}) \tag{1}$$

where LF is mean lung function, H height, c the parameter for H and A age. By taking logarithms of both sides of the multiplicative model, the model can be converted to a logarithmic additive model:

$$\ln \mathrm{LF} = c \ln \mathrm{H} + \ln f(\mathrm{A}) \tag{2}$$

Expressing the model in this way allows the model to be fitted using standard linear multiple regression techniques.

Six multiplicative models were fitted to the HSE data: FEV1, FVC, and FEV1/FVC, each for males and females separately. The fitting of the multiplicative model to the data was an iterative process. Firstly, the form of the age function of the equation was established, the best fit for all models being found to be quadratic.

Once the preliminary models had been fitted, they were tested for goodness of fit over the full height and age ranges, mean predicted lung function by age and height being checked against mean observed lung function. This analysis suggested that the models were a reasonably close fit across the height range for both males and females, and a reasonably close fit across the age range for females, although there was some suggestion that the models fitted slightly less well for older females. However, comparing observed and predicted means by age for males revealed a systematic mismatch between the predicted and observed means for younger males aged up to 25 yrs.

To improve the fit of the models for males, they were refitted using piecewise regression, one regression equation being fitted for males aged ≤25 yrs, and a second for those aged ≥25 yrs. The two equations were constrained such that both models gave the same predicted value at the point at which they met, *i.e.* for those aged 25 yrs. Dividing the regression equation in this way led to a significant improvement in goodness of fit for FEV1 and FVC.

Prediction equations for the fifth percentile (lower limit of normal). By convention, an individual's lung function is taken to be "low" if they have a lung function value (for either FEV1 or FVC) below the fifth lung function percentile (lower limit of normal) for "healthy" persons of equivalent sex, age and height [12]. If individual observations by age and height for the "healthy" population have a distribution close to Gaussian, and the residuals show the same SD by age and height, the value of the fifth percentile can be estimated approximately from the regression model as:

$$\text{5th percentile} \sim \text{predicted mean} - 1.645\sigma \tag{3}$$

where σ is the SD of the residuals around the predicted mean (and a residual is the difference between observed and predicted lung function). The distributions of FEV1 and FVC in population studies are usually found to meet the Gaussian/equal SD criteria in the middle age range, but not at the extremes [7]. The use of Equation 3, when the criteria are not met, leads to misclassification of "low" lung function; some people are wrongly classified as "low" and others as "within the normal range". This misclassification is particularly large at the extremes of the age range.

The "natural" alternative, which is to make a direct estimate from the survey data of the fifth percentiles for each combination of height, age and sex, is not feasible because of the small sample numbers within each combination; the resulting estimates would be far too unstable (*i.e.* would vary between samples if the survey were repeated).

An alternative model-based approach is to directly estimate the fifth percentiles by age and sex and then to "smooth" these estimates using regression techniques [9]. This is the method used by BRÄNDLI *et al.* [1].

In order to apply this approach to the HSE data, individuals (within-sex) were sorted by age. The fifth percentile of the residuals was then calculated for the first 200 sorted cases and saved. The first case was then dropped and the 201st case picked up, and a second fifth percentile calculated and saved. The second case was then dropped and the 202nd case picked up, and a third fifth percentile calculated and saved. This process was continued until the end of the data set was reached, giving a rolling series of percentiles.

In the next stage, the rolling percentiles were regressed against mean age and mean age squared (from the same 200 cases) to give:

$$5^{\text{th}}\ \text{percentile of the residuals} = a + b_1\text{A} + b_2\text{A}^2 \quad (4)$$

where a is a constant and b_1 and b_2 are the coefficients for A and A^2. In all models for FEV1, FVC and FEV1/FVC, b_2 was found to be significant (males and females separately).

The prediction equations for the lower limit of normal (LLN) were obtained by combining Equation 4 with the equation for the mean.

Comparison with other prediction equations. The fitness of use of the present prediction equations was ascertained by comparing the goodness of fit obtained using the present equations with those obtained using both recently published sets of prediction equations [1, 13, 14] and those from the ECSC, applying all sets of equations to the present study population.

The measures used in the comparison were the mean difference between observed and predicted values, the mean difference as a percentage of the mean observed value and the mean squared difference.

Results

After selection of healthy nonsmoking people who met the ATS reproducibility criteria, a total of 2,497 males and 3,556 females were included in the study (table 1). It is worth noting that the sample size decreased considerably at ages >75 yrs, particularly amongst males. On the basis of the selection, only 6% of males and 9% of females aged ≥75 yrs were included in the study compared to 20% of males and 24% of females aged <75 yrs.

Preliminary investigation revealed a strong relationship between FEV1 and FVC and age and height but no relationship between lung function and weight or body mass index. For this reason, the prediction equations did not include weight or body mass index as predictors. For males, the relationship between age and both FEV1 and FVC was clearly quadratic: lung function increased slightly with age between the ages of 16 and ~25 yrs, after which there was a decline with age. For females, there was some suggestion of a similar pattern above the age of 25 yrs as for males, but, between the ages of 16 and 25 yrs, there was a small negative relationship between lung function and age, albeit a weaker relationship than for older females (fig. 1).

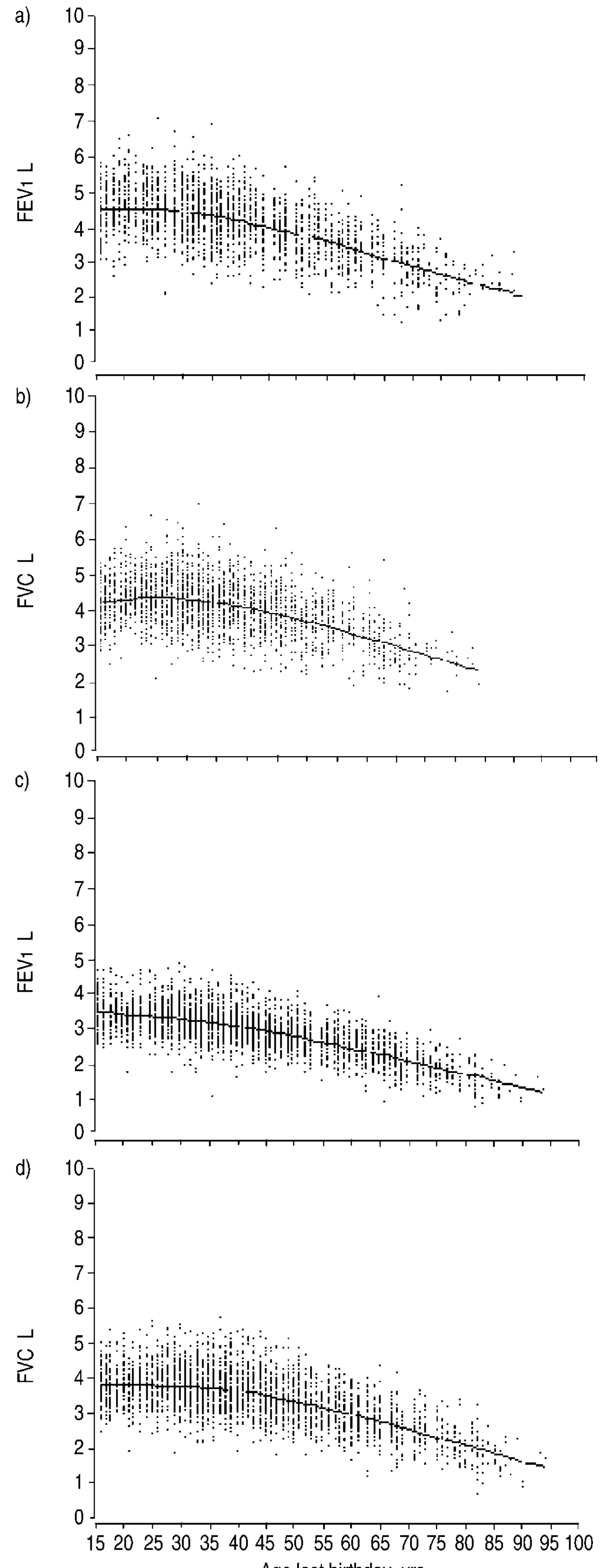

Fig. 1. – Age dependency of forced expiratory volume in one second (FEV1) (a, c) and forced vital capacity (FVC) distribution (b, d) in males (a, b) and females (c, d). Each subject is represented by a dot (——: smoothed values (lowess)).

Table 2. – Coefficients from prediction equations for normal lung function measures by sex

	b_0	b_1	b_2	b_3
Corresponding variable	Intercept	A	A^2	ln H
ln FEV1 L				
Males (R^2=0.59; σ=0.14)				
Mean				
Age ⩽25 yrs	-10.41186	0.09569	-0.00221	2.10839
Age >25 yrs	-9.37674	0.00183	-0.00011	2.10839
LLN				
Age ⩽25 yrs	-10.75820	0.10320	-0.00231	2.10839
Age >25 yrs	-9.72308	0.00933	-0.00021	2.10839
Females (R^2=0.69; σ=0.14)				
Mean	-8.49717	0.00422	-0.00015	1.90019
LLN	-8.68467	0.00495	-0.00018	1.90019
ln FVC L				
Males (R^2=0.52; σ=0.14)				
Mean				
Age ⩽25 yrs	-11.45146	0.09895	-0.00216	2.32222
Age >25 yrs	-10.36706	0.00434	-0.00011	2.32222
LLN				
Age ⩽25 yrs	-11.63230	0.09795	-0.00217	2.32222
Age >25 yrs	-10.54790	0.00334	-0.00012	2.32222
Females (R^2=0.62; σ=0.15)				
Mean	-9.66999	0.00837	-0.00017	2.14118
LLN	-9.84941	0.00772	-0.00018	2.14118
ln FEV1/FVC				
Males (R^2=0.15; σ=0.08)				
Mean	1.03981	-0.00394	0.00002	-0.21653
LLN	0.82621	0.00101	-0.00005	-0.21653
Females (R^2=0.16; σ=0.08)				
Mean	1.15822	-0.00415	0.00002	-0.23815
LLN	1.00699	-0.00196	-0.00001	-0.23815

Model: mean lung function=$e^{b0+b1A+b2A2+b3\ln\ H}$. For example, a male aged 31 yrs with a height of 173 cm would have a predicted forced expiratory volume in one second (FEV1) of 4.53 L (from $e^{-9.37674+(0.00183\times31)-(0.00011\times312)+2.10839\ln173}$), and a predicted forced vital capacity (FVC) of 5.48 L (from $e^{-10.36706+(0.00434\times31)-(0.00011\times312)+2.32222\ln173}$). R^2: fraction of explained variance; σ: SD of residuals; LLN: lower limit of normal; A: age; H: height.

The relationship between height and FEV1 and FVC was much less clear, but can be described as broadly linear with a positive gradient.

The best fit for the age function was found to be quadratic for all lung function measurements, *i.e.* FEV1, FVC and FEV1/FVC. Thus the models can be expressed in the general form:

$$\text{predicted LF} = e^{b0 + b1\text{A} + b2\text{A2} + b3\ln \text{H}} \tag{5}$$

This form holds for both the predicted mean and the predicted LLN. The coefficients are shown in table 2. It is worth noting that, although the sample includes a wide height and age range (table 1), the extremes were found not to be influential points for the equations.

The mean minus 1.645σ approach, generally used in reference equations for lung function, implies that Equation 4 (the equation for the fifth percentile of the residuals) is constant (*i.e.* Equation 4 would take the form 5th percentile of the residuals=*a* rather than that shown). The significant dependence of the percentiles on age supports the view that the mean minus 1.645σ approach is inadequate in the present sample. The prevalence estimates of people with lung function below the LLN, using the mean minus 1.645σ approach, increase with age and are significantly different from the ones derived from the equation for the fifth percentile (table 3). This is particularly true for people aged ⩾65 yrs. Therefore,

Table 3. – Percentage of population with lung function below the lower limit of normal in "healthy" population for the Health Survey for England reference curves using different estimates of the 5th percentile by sex and age group

Age yrs	Present model#		Mean – 1.645σ	
	FEV1	FVC	FEV1	FVC
Males				
16–24	4.0	5.0	4.5	4.0
25–34	5.8	5.0	5.0	3.9
35–44	6.3	6.0	5.3	6.3
45–54	3.5	5.1	4.3	6.6
55–64	3.1	3.8	6.9	6.9
65–74	6.4	6.4	12.1	10.8
⩾75	5.1	5.1	8.5	15.3
All	5.0	5.2	5.6	5.9
Females				
16–24	5.5	6.1	3.0	3.7
25–34	4.6	5.7	3.2	3.2
35–44	6.3	4.4	4.9	4.1
45–54	5.1	5.4	5.6	5.9
55–64	5.3	6.7	6.5	7.9
65–74	5.5	5.2	10.9	9.1
⩾75	5.7	3.8	13.8	10.7
All	5.4	5.4	5.5	5.4

σ: SD of residuals; FEV1: forced expiratory volume in one second; FVC: forced vital capacity. #: lower limit of normal=$e^{b0+b1A+b2A2+b3\ln\ H}$; coefficient values given in table 2.

unlike other studies, the inclusion of older age groups in the sample makes the direct estimate of the fifth percentile necessary. Figure 2 shows predicted mean lung function and predicted fifth percentile by age. The difference between the fifth percentile and mean FEV1/FVC increases considerably in the elderly. This is because lung function varies more with increasing age.

The definition of LLN is such that, for any combination of age and height, ~5% of the "healthy" White adult population should fall below the LLN. A natural check on the goodness of fit of the models for LLN is to estimate this percentage for particular age and height groups (table 4). As might be expected (after all, reasonably parsimonious models rarely fit data perfectly), there is some variation in the percentages with lung function below the LLN in the healthy population by age group using the HSE equations. Nevertheless, the percentages do not differ significantly (*i.e.* the variation can be attributed to sampling error) and the variation is considerably lower than that associated with use of the ECSC equations.

The difference in mean predicted value between the present study and ECSC reference values demonstrates that the ECSC equations systematically underestimate both mean FEV1 and FVC (FVC underestimation shown in figure 3). Similarly, comparing the prevalence estimates of lung function below the LLN for both the healthy and whole (including nonhealthy subjects) populations, the prevalence estimates based on the HSE equations can be seen to be systematically higher than the ones based on the ECSC equations (table 4).

Much better agreement of mean FEV1 and FVC estimates was found between the present study and prediction equations from other recent studies (fig. 4). All nonlinear equations fitted the data from the HSE quite well, whereas, as noted above, the ECSC equations underestimated both FEV1 and FVC (table 5).

Greater differences were found in mean FEV1/FVC

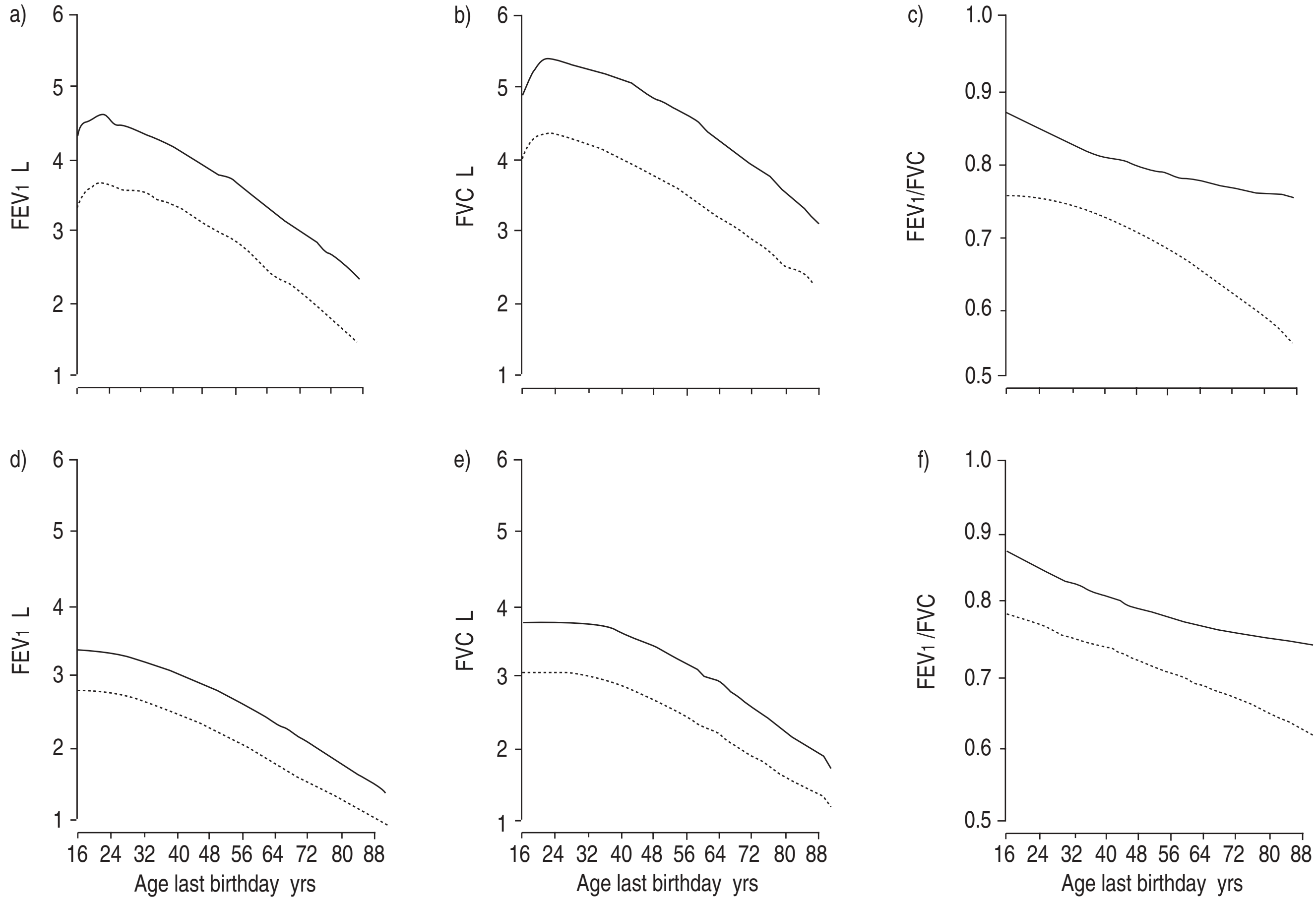

Fig. 2. – Predicted mean (——) and fifth percentile (·········) for forced expiratory volume in one second (FEV1) (a, d), forced vital capacity (FVC) (b, e) and FEV1/FVC (c, f) in males (height 175 cm) (a–c) and females (height 165 cm) (d–f) by age.

between the different sets of prediction equations, especially in the elderly (fig. 5). All other mean prediction equations, except those of LANGHAMMER *et al.* [13], showed a greater decrease by age among the elderly than the present study.

In order to test the robustness of the present model, it would be useful to check that the prevalence of values below the LLN is close to 5% for various sex, age and height combinations in the "healthy" White adult population across other years of the survey. Lung function was measured again in the 1997 HSE, but the data collected in that survey did not permit subdivision of respondents into "healthy" and "nonhealthy", and so any checks of robustness have to be based on the whole White adult population rather than the "healthy" subset of this group. Comparing the prevalence of people with lung function values below the LLN by sex and age group for the 3 yrs, 1995, 1996 and 1997, the results for 1997 appeared very similar to those from previous years. This suggests reasonable robustness (data not shown).

Discussion

The present article describes the derivation of lung function reference curves from the 1995 and 1996 Health Surveys for England. Prevalence estimates of people with lung function below the LLN for "healthy" and "nonhealthy" populations, by age and sex, were presented in both the 1995 and 1996 HSE reports [5, 15]. These prevalence estimates were derived using ECSC equations, which were acknowledged at the time to give biased estimates. New reference equations were, therefore, estimated from the present nationally representative population sample. One of the strengths of the current study is its size and representativeness, including a substantial proportion of elderly subjects (aged $\geqslant$65 yrs), who were underrepresented in previous studies.

Usually, adult reference values are used from the age of 18 yrs onwards, although this does not reflect the relationship between age, lung function growth and body size. Indeed, although adult lung size is attained at ~16 yrs among females, growth continues up to ~24–25 yrs in males [16]. In the present study, individuals were included from the age of 16 yrs, but, to provide prediction equations of good fit, two equations were fitted for male subjects, one for those aged $\leqslant$25 yrs and one for those aged >25 yrs. This decision was driven by looking at the data, but, in retrospect, it also better reflects the biological relationship between age, height and pulmonary function test results.

The new prediction equations, derived from a large sample of asymptomatic never smoking people aged 16–94 yrs, predicted mean FEV1 and FVC very well in the present population. Moreover, the LLN was estimated directly using a smoothing technique; this gave more accurate estimates

Table 4. – Percentage of population defined as exhibiting lung function below the lower limit of normal (LLN) in "healthy" and whole populations using the Health Survey for England (HSE) and European Coal and Steel Community (ECSC) reference curves by sex and age group[#]

Age yrs	HSE[¶]				ECSC[+]			
	Healthy		Whole		Healthy		Whole	
	FEV1	FVC	FEV1	FVC	FEV1	FVC	FEV1	FVC
Males								
18–24	4.9	4.6	7.4	7.7	4.3	3.0	5.8	5.1
25–34	5.8	5.0	8.8	7.4	3.1	2.6	5.5	4.5
35–44	6.3	6.0	12.5	8.8	2.6	2.6	6.3	4.5
45–54	3.5	5.1	15.1	10.2	0.5	1.6	8.3	5.4
55–64	3.1	3.8	17.7	12.7	1.2	1.5	12.0	8.9
65–70	7.5	7.5	22.8	17.1	5.7	3.8	18.1	13.0
All	5.2	5.2	13.4	10.0	2.6	2.4	8.4	6.2
Females								
18–24	4.7	5.8	9.7	7.8	1.7	3.3	5.1	4.9
25–34	4.6	5.7	9.1	7.2	2.4	1.9	4.3	3.4
35–44	6.3	4.4	12.5	9.5	1.9	0.9	5.1	3.4
45–54	5.1	5.4	13.8	10.1	1.7	0.7	5.3	2.8
55–64	5.3	6.7	17.5	13.9	1.7	1.2	8.9	4.8
65–70	4.8	5.3	17.8	13.8	1.0	1.0	9.6	5.5
All	5.2	5.5	12.9	9.9	1.9	1.4	5.9	3.9

#: range restricted to 18–70 yrs, as recommended for the ECSC prediction equations, to permit comparison. FEV1: forced expiratory volume in one second; FVC: forced vital capacity. ¶: LLN computed from mean lung function=$e^{b0+b1A+b2A2+b3\ln H}$; coefficient values given in table 2; +: LLN computed from mean – 1.645σ.

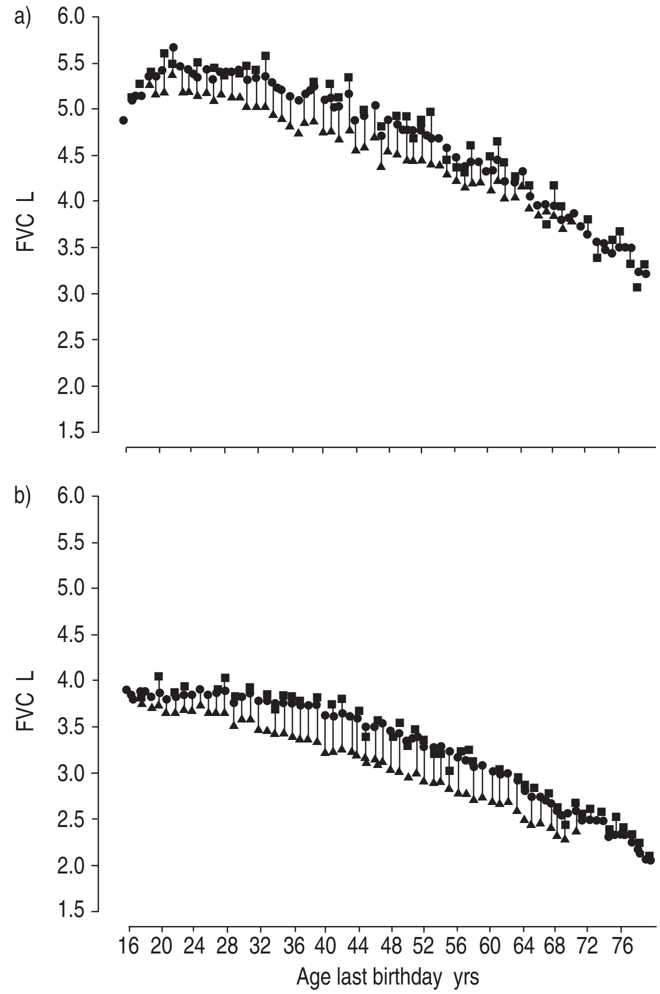

Fig. 3. – Observed (■) and predicted (●) mean forced vital capacity (FVC) in present study and European Coal and Steel Community reference values (▲) by age in a) males and b) females.

than assuming a constant difference (1.645σ) between the mean and the fifth percentile.

A comparison of several prediction equations for spirometry has shown substantial agreement using the fifth percentile criterion, but not using the mean minus 1.645σ criterion [17]. The ATS recommends that normal ranges should be based on calculated fifth percentiles, whereas estimates of fifth percentiles based on the -1.645σ criterion are acceptable for indices with distributions that are close to Gaussian [18]. As the HSE lung function data showed some indication of non-normality of distribution of residuals and nonconstant variance by age, especially in older groups, direct estimates of the fifth percentiles were derived instead. Thus the probability of declaring a healthy person as showing "low" lung function is independent of age.

Using the paired t-test, the mean FEV1 and FVC predicted by the ECSC were found to be significantly different ($p<0.001$) from those predicted by the new equations for both males and females. The present study confirmed the underestimation of lung function parameters using ECSC equations. Conversely, the new equations for FEV1 and FVC showed close agreement with other nonlinear equations derived from recent studies, all of which indicated higher levels of predicted lung function parameters than predicted by ECSC equations. Among older people (aged ⩾65 yrs), the present predicted mean FEV1/FVC was higher than in other studies [1, 4, 14]; this could be due to the presence of very healthy elderly survivors. Conversely, the estimated fifth percentile allows the greater variability among the elderly to be accounted for and provides a good estimate of the LLN.

Hardie *et al.* [19] have shown that the use of a fixed FEV1/FVC cut-off point (0.7) for defining chronic obstructive pulmonary disease, as recommended by the Global Initiative for Chronic Obstructive Lung Disease [20], may lead to a significant degree of overdiagnosis of both the presence and severity of chronic obstructive pulmonary disease in the elderly proportion of the population. Consistently with that study, the present prediction equations indicate that a lower FEV1/FVC ratio should be used in the elderly. For example, based on the prediction equations from the present study (table 2), a 70-yr-old male with a height of 170 cm has a LLN for FEV1/FVC of 0.63, falling to 0.59 at 80 yrs and 0.55 at 90 yrs.

The present new reference curves are a significant improvement over the European Coal and Steel Community reference curves currently used in the primary analysis of Health Survey for England data. Their use, in future years, in the analysis of the Health Survey for England should ensure, firstly, that prevalence estimates of people with lung function below the lower limit of normal are free of the bias acknowledged to exist in the current estimates, and, second (although the two points are closely related), that comparisons across subgroups are fair. The results of the present study also have clear clinical implications, given that everyday decisions are made with regard to diagnosis, treatment and prevention of respiratory condition on the basis of lung function results in relation to reference values. It is, therefore, suggested that, in both epidemiological and clinical settings, the present equations based on the White English population should be used in preference to those of the European Coal and Steel Community.

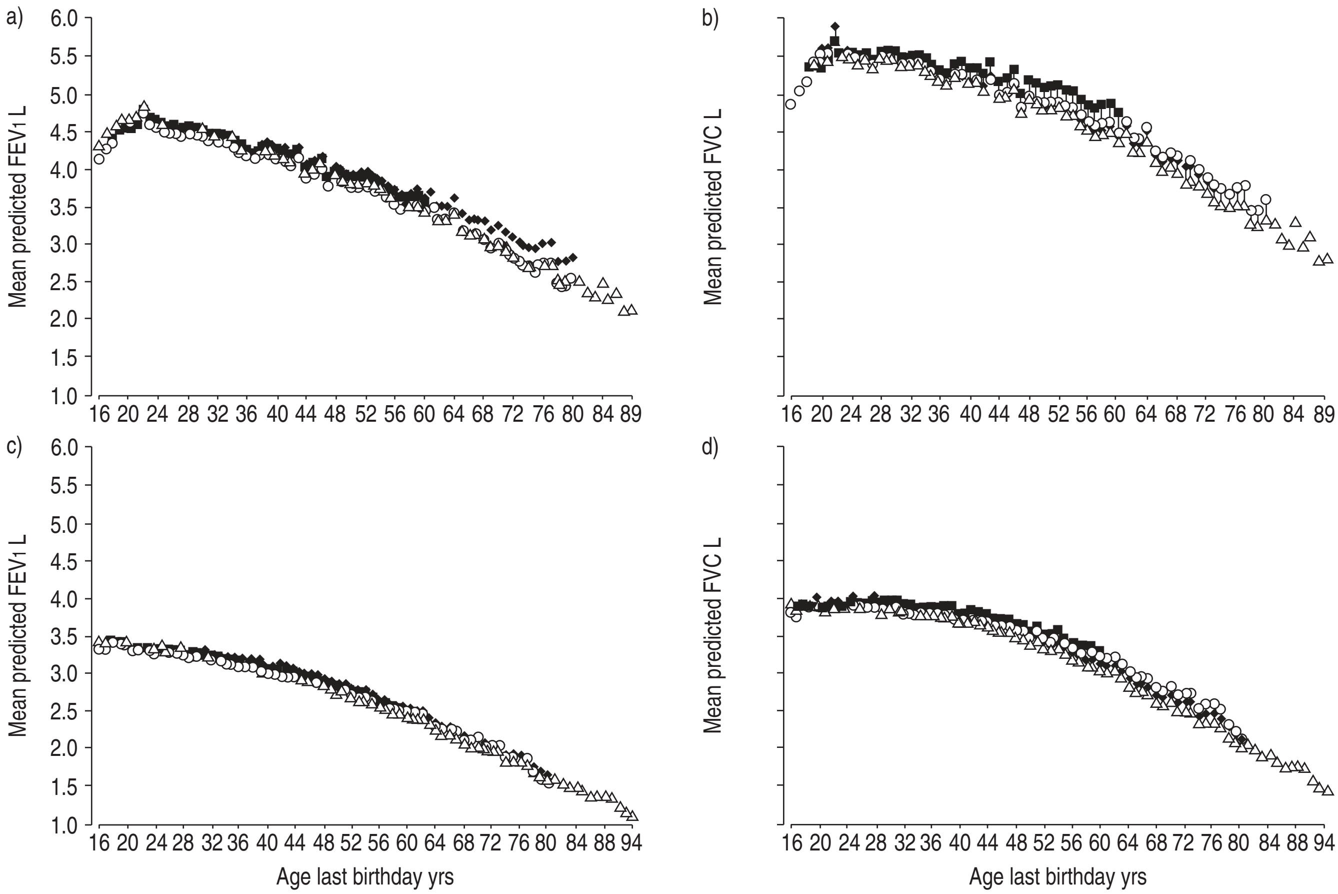

Fig. 4. – Comparison of mean predicted forced expiratory volume in one second (FEV_1) (a, c) and forced vital capacity (FVC) (b, d) by age in males (a, b) and females (c, d) in present study (△) and studies of BRÄNDLI *et al.* [1] (■), LANGHAMMER *et al.* [13] (◆) and HANKINSON *et al.* [14] (○).

Table 5. – Mean differences and mean differences squared between values observed in the present study and predicted by various prediction equations

First author [ref.]	Age yrs	Males				Females			
		Subjects n	Mean DIFF	Mean DIFF %	Mean squared DIFF	Subjects n	Mean DIFF	Mean DIFF %	Mean squared DIFF
FEV_1									
Present study	16–94	2479	0.04	0.86	0.28	3556	0.03	0.87	0.14
BRÄNDLI [1]	18–60	2056	0.00	0.04	0.29	2755	-0.01	-0.33	0.15
LANGHAMMER [13]	20–80	2249	-0.06	-1.56	0.29	3249	-0.06	-2.09	0.15
HANKINSON [14]	16–80	2459	0.07	1.64	0.29	3489	0.02	0.69	0.15
ECSC [4]	18–70	2250	0.25	6.01	0.35	3129	0.20	6.77	0.19
FVC									
Present study	16–94	2479	0.04	0.88	0.44	3556	0.03	0.97	0.23
BRÄNDLI [1]	18–60	2056	-0.14	-2.77	0.48	2755	-0.11	-3.00	0.26
LANGHAMMER [13]	20–80	2249	-0.05	-0.92	0.46	3249	-0.07	-2.06	0.24
HANKINSON [14]	16–80	2459	-0.04	-0.81	0.45	3489	-0.04	-1.09	0.24
ECSC [4]	18–70	2250	0.34	6.62	0.57	3129	0.35	9.73	0.37
FEV_1/FVC									
Present study	16–94	2479	0.0016	0.19	0.0043	3556	0.0048	0.57	0.0042
BRÄNDLI [1]	18–60	2056	0.0225	2.73	0.0045	2755	0.0210	2.51	0.0044
LANGHAMMER [13]	20–80	2249	-0.0026	-0.32	0.0045	3249	0.0056	0.68	0.0044
HANKINSON [14]	16–80	2459	0.0223	2.72	0.0048	3489	0.0156	1.87	0.0045
ECSC [4]	18–70	2250	0.0199	2.43	0.0046	3129	0.0229	2.74	0.0046

FEV_1: forced expiratory volume in one second; FVC: forced vital capacity; ECSC: European Coal and Steel Community; DIFF: difference.

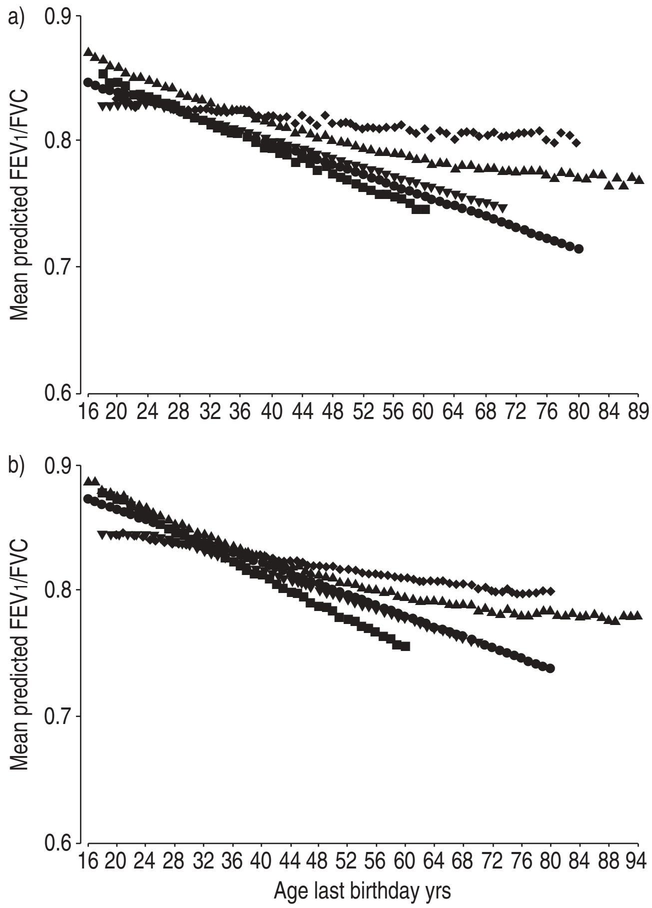

Fig. 5. – Comparison of mean predicted forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) by age in a) males and b) females in the present study (▲) and studies of BRÄNDLI *et al.* [1] (■), LANGHAMMER *et al.* [13] (◆), HANKINSON *et al.* [14] (●) and European Coal and Steel Community [4] (▼).

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