



Reference equations for lung function screening of healthy never-smoking adults aged 18–80 years

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ABSTRACT: The need for updated spirometric reference values to be used on European populations is widely acknowledged, especially for subjects aged >70 yrs. Their reference values are generally based on extrapolations. The aim of the present study was to calculate reference values for lung function screening of healthy, never-smoking adults aged 18–80 yrs and to compare them with the most widely used reference equations.

Results of screening spirometry of 8,684 healthy, never-smoking adults were used to calculate mean values and fifth percentiles of lung function variables.

The European Community of Coal and Steel (ECCS) reference equations underestimate forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC). For example, in 50-yr-old males (height 175 cm), lower limits of normal for FEV₁ are underestimated by 198 mL, and for FVC by 210 mL. In 50-yr-old females (height 165 cm), lower limits of normal for FEV₁ are underestimated by 191 mL, and for FVC by 270 mL. The decline of FVC in elderly subjects is steeper than predicted by the ECCS.

Reference equations derived from spirometry data locally collected in a practical setting by well-trained personnel might be more appropriate for everyday use than generally used equations based on data from scientific studies in the distant past.

KEYWORDS: Aged, pulmonary function, reference equations, spirometry

The comparison of results of lung function tests with normal values may influence decisions that have important implications both for individuals and for the healthcare system. Several sets of normal values have been published over the last decades and “normality” for a given age and height varies considerably across these studies. Such variations may be explained by the selection criteria of “normal” populations, cohort effects, measurement techniques and devices, biological variability across populations and statistical modelling [1–3]. Major arguments for updating reference values on a regular basis are birth cohort effects (*e.g.* changes in the distribution of lung function at a given age over time) and new technical equipment [4]. If no updating is performed, normal values may gradually lose their sensitivity in detecting abnormal conditions at an early stage.

Standardisation procedures have been improved and computer-based equipment allows *ad hoc*

decisions with regard to acceptability and reproducibility of spirometric manoeuvres [5, 6].

The European Community of Coal and Steel (ECCS) prediction equations, which are most widely used in Europe, were derived from lung function measurements of subjects, including smokers, studied in the years 1954–1980, from different study populations and from several data sets. Thus their value for the interpretation of spirometric tests has been challenged [7–9]. Current guidelines do not recommend a specific set of equations for use in Europe. There is a major need for new studies to derive updated reference equations for lung function, especially for elderly persons [10]. Recent recommendations on equipment and standardisation of procedures propose reference values based on cross-sectional studies of lifetime nonsmokers [2, 5, 8]. It has been shown that wheeze, breathlessness and cough influence lung function parameters, whereas chronic phlegm was not associated with

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airway obstruction or reduced forced expiratory volume in one second (FEV₁) in some surveys, suggesting that perhaps not all respiratory symptoms need to be accounted for when defining a healthy reference population used to derive reference values [3].

Most reference equations used in North America and Europe have been derived from studies that included relatively small numbers of individuals aged >65 yrs. Only a few sets of equations have been published for elderly lifetime nonsmokers of Caucasian-American origin [11–13]. Since international guidelines discourage the use of spirometry reference equations for ages or heights outside the range covered by the data that generated them, there is a need to collect lung function data from elderly persons [2, 14].

In the present study, the results provided are based on a large cross-sectional sample from a Central European population. The present study is unique in that empirically based reference equations of forced spirometry are presented for subjects aged 18–80 yrs. The reference equations used in the present study for the means and the fifth percentiles as lower limits of normal range account for changes in the distribution of lung function with age and height. Reference values from the present study are compared for the entire age range with those from the Swiss Cohort Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), those from the ECCS and those from the third National Health and Nutrition Examination Survey (NHANES III) [7, 15–17]. Reference values for elderly subjects are compared with other reference sets that were derived for individuals aged >65 yrs [11, 13, 17–19].

METHODS

In the present cross-sectional study, lung function test results collected by the “LuftiBus” team in the greater Zurich metropolitan area (Zurich, Switzerland) between December 2000 and August 2005 were analysed. The LuftiBus project is maintained by the Lung Association of Zurich. It consists of a bus equipped with two flow-sensing spirometers that tours mainly the greater Zurich area and offers spirometry measurements to the general public. Spirometry data are recorded electronically along with data from a standardised interviewer-administered questionnaire collecting basic information on the health and lifestyle of subjects. Lung function tests are charged at 10 CHF to adults to cover the costs on a nonprofit basis.

Reference population

From a total of 20,460 subjects, 8,684 were included in the sample used to derive normal values for spirometric parameters (table 1). Subjects were excluded if they met at least one of the exclusion criteria (table 2). Never-smokers were defined as subjects with a cumulative smoking history of <1 pack-yr (a pack-yr is defined as years of smoking × the number of cigarettes smoked per day divided by 20). Due to the ongoing migration in Europe and mixture of ethnical backgrounds, and due to the very small proportion of non-Caucasian people in Switzerland, no exclusion was made based on race or nationality [20]. Thus, ethnicity was not assessed systematically for the whole study population. Ethnicity was recorded in a subset of 3,061 consecutive subjects of the reference sample (1,356 males and 1,705 females) measured in the years 2004 and 2005 and, thereof, non-Caucasian subjects accounted for 19 (1.1%) females and 17 (1.3%) males.

TABLE 1 Inclusion characteristics for study population

	Males	Females	Total
Subjects n	9738	10722	20460
Health criteria satisfied	7371 (75.7)	7803 (72.8)	15174 (74.2)
Never-smokers	4565 (46.9)	7009 (65.4)	11574 (56.6)
All criteria satisfied	3512 (36.1)	5172 (48.2)	8684 (42.4)

Data are presented as n (%), unless otherwise stated.

Spirometry

During the time of data collection, the LuftiBus was equipped with two computerised pneumotachographs (SensorMedics® Vmax Legacy 20c spirometer run by Vision 7-2b software; VIASYS, Yorba Linda, CA, USA). The volume signal of the equipment was calibrated at least once daily with a 3-L syringe. Tests were performed in a sitting position according to American Thoracic Society (ATS) guidelines without nose-clips after an oral instruction by the technician [2, 14]. Participants were assisted by eight specially trained lung function technicians who performed immediate on-screen evaluation of major acceptability criteria (including start, duration and end of test) in addition to the automated review performed by the computer software. As recommended by the ATS in 1994 [14], data that did not meet reproducibility criteria were not excluded, but subjects were asked to perform up to a maximum of eight manoeuvres in an attempt to obtain reproducible results. From a minimum of two acceptable tests, the largest forced vital capacity (FVC) and FEV₁ were selected, regardless of the manoeuvre. All other parameters were taken from the trial with the largest sum of FVC and FEV₁. Self-reported values for height were used.

Statistical methods

The methodology used by the SAPALDIA team was reproduced. In a first step, prediction equations for the mean were estimated. Equations for the fifth percentiles, which were the

TABLE 2 Exclusion criteria

Former or current smokers ≥1 pack-yrs
Current acute respiratory disease
Common cold
Acute bronchitis
Current respiratory symptoms
Cough
Wheezing
Shortness of breath with rest or exertion
Phlegm
History of asthma
Current treatment with asthma medication
History of chronic obstructive pulmonary disease or chronic bronchitis
History of other lung diseases
Lung operations
Pulmonary embolism

primary focus of interest as lower limits of the normal range, were then estimated from the residuals of the models for the mean. All regression models were stratified by sex. The methods have been described in detail previously [15, 16].

Prediction equations for the mean

To estimate equations for the mean, the natural logarithms of lung function variables were regressed against ln(height), age and quadratic function of age. The rationale for considering lung function variables on the logarithmic scale was the assumption that the dependency of average lung function (LF) on height (H) and age (A) is suitably described by a function of the form:

LF=H^c × f(A) (1)

Whereas estimating the exponent c from the untransformed data requires the solution of a nonlinear regression problem, the logarithmic transformation of the equation turns the regression problem for c into a linear one. The piecewise quadratic model was only retained if its fit was significantly better than the one of a simple quadratic model defined over the entire interval. If such a simplified model proved to be sufficiently adequate, it was also tested whether or not the quadratic age term was statistically significant.

Prediction equations for fifth percentiles

The next step was to compute fifth percentiles according to a new method for estimating percentile curves using weighted L₁ regression. Thus, instead of minimising the sum of squared residuals, a weighted sum of the absolute values of the residuals was minimised. These residuals were again regressed against age. If:

y=α + β × A (2)

denotes the estimated regression line for the fifth percentile of

r=ln(LF_{observed}/LF_{predicted}) (3)

as a function of age, then;

y=LF_{predicted} × exp(α + β × A) (4)

is an estimate of the fifth percentile of lung function for a given age. To test whether a linear age term was sufficient to describe the age dependency of the fifth percentile of r, an indicator variable U was defined taking the value of 1 for residuals:

r ≤ α + β × A (5)

and the value 0 for residuals:

r > α + β × A (6)

and a logistic regression model for U in terms of the covariates A and A² was computed. The quadratic term did not reach statistical significance for any of the lung function parameters considered, thus suggesting that the model with the linear age term was sufficient throughout. In an analogous way, it could be verified that the fifth percentile of r did not significantly depend on the height of the individual.

Comparisons of reference equations

The newly derived reference equations were compared with those most widely used in Europe (ECCS) and the USA

(NHANES III), as well as the most recent Swiss reference values (SAPALDIA) [8, 15–17]. In addition, in order to especially address the concerns that might arise due to the possible over-reporting of height in elderly patients, reference values of 65–80-yr-old subjects were compared with several sets of reference equations that were recently published for this population [11, 13, 17–19].

RESULTS

The main characteristics of the study population are shown in table 3. Demographic data of the 8,684 subjects show an over-representation of females satisfying the inclusion criteria because females were more likely to have never smoked than males and females were, to a lesser extent, over-represented in the study sample.

The prediction equations for the mean of the lung function variables are displayed in table 4 as:

LF=exp(a + b × ln(H) + c₁ × A + c₂ × A²) (7)

where LF represents any of the lung function variables measured (FVC, FEV₁, FEV₁/FVC, maximal instantaneous forced expiratory flow when 75% of the FVC remains to be exhaled (MEF₇₅), maximal instantaneous forced expiratory flow when 50% of the FVC remains to be exhaled (MEF₅₀), and maximal instantaneous forced expiratory flow when 25% of the FVC remains to be exhaled (MEF₂₅)). This equation is equivalent to:

ln(LF)=a + b × ln(H) + c₁ × A + c₂ × A² (8)

The equations for the fifth percentiles, which are generally recommended as a lower limit of the normal range, are displayed in table 5. They are of the same form as those for the mean. The ranges of application for these reference equations are ages 18–80 yrs and heights of 140–200 and 130–190 cm in males and females, respectively.

The choice of two age intervals (one for the ages 18–25 yrs and one for the interval >25 yrs) was suggested by the ECCS, who had modelled lung function by a piecewise linear function of age. The SAPALDIA team had found that, even with a

TABLE 3 Height characteristics and age distribution of reference sample		
	Males	Females
Subjects n	3512	5172
Height* cm	176.3 ± 7.4	163.3 ± 6.8
Age* yrs	47.3 (18.2)	52.9 (17.5)
<30	742 (21.1)	625 (12.1)
30–39	525 (14.9)	649 (12.5)
40–49	659 (18.8)	821 (15.9)
50–59	592 (16.9)	936 (18.1)
60–69	504 (14.4)	1119 (21.6)
70–79	376 (10.7)	822 (15.9)
>79	114 (3.2)	200 (3.9)
Data are presented as mean ± sd or n (%), unless otherwise indicated. #: self-reported values were used.		

TABLE 4 Prediction equations for the means of lung function variables

Equation		R ² #
Males		
FVC L	$\exp(-10.258+2.280 \ln(H)+0.00676A-0.000124A^2)$	0.549
FEV ₁ L	$\exp(-8.957+2.014 \ln(H)+0.00281A-0.000105A^2)$	0.639
MEF ₇₅ L·s ⁻¹	$\exp(-2.227+0.812 \ln(H)+0.00977A-0.000132A^2)$	0.108
MEF ₅₀ L·s ⁻¹	$\exp(-3.055+0.911 \ln(H)+0.00249A-0.000109A^2)$	0.226
MEF ₂₅ L·s ⁻¹	$\exp(-3.970+1.009 \ln(H)-0.01645A-0.000020A^2)$	0.419
FEV ₁ /FVC %	$\exp(+6.291-0.341 \ln(H)-0.00441A+0.000026A^2)$	0.126
PEF L·s ⁻¹	$\exp(-3.760+1.170 \ln(H)+0.00706A-0.000110A^2)$	0.233
Females		
FVC L	$\exp(-9.069+2.013 \ln(H)+0.00847 A-0.000155A^2)$	0.562
FEV ₁ L	$\exp(-8.397+1.865 \ln(H)+0.00570 A-0.000150A^2)$	0.526
MEF ₇₅ L·s ⁻¹	$\exp(-2.716+0.867 \ln(H)+0.00963 A-0.000140A^2)$	0.184
MEF ₅₀ L·s ⁻¹	$\exp(-2.131+0.674 \ln(H)+0.00895 A-0.000180A^2)$	0.253
MEF ₂₅ L·s ⁻¹	$\exp(-4.861+1.145 \ln(H)-0.01120 A-0.000096A^2)$	0.423
FEV ₁ /FVC %	$\exp(+5.637-0.219 \ln(H)-0.00249 A+0.000004A^2)$	0.039
PEF L·s ⁻¹	$\exp(-4.794+1.316 \ln(H)+0.00926 A-0.000143A^2)$	0.329

FVC: forced vital capacity; FEV₁: forced expiratory volume in one second; MEF₂₅ or 50 or 75: maximal instantaneous forced expiratory flow when 25, 50 or 75% of the FVC remains to be exhaled, respectively; PEF: peak expiratory flow; H: height (cm); A: age (yrs); exp(x): e^x. #: fraction of explained variance.

quadratic function of age, a separate model for subjects aged <25 yrs was warranted [8, 21]. However, in the present study, separate equations did not fit the data significantly better than a single equation. Results for each lung function variable refer to participants who performed the tests according to ATS quality criteria [14].

Comparisons with the reference equations provided by the ECCS for 18–70-yr-old subjects and the recently published Swiss values for subjects aged 18–60 yrs are shown in figure 1 for males and in figure 2 for females [15]. However, the present sample included a considerable number of subjects aged >70 yrs, so that the estimation of reference equations could be extended to the age of 80 yrs.

In males as well as in females, the volumes predicted by reference equations for the fifth percentile of FEV₁ from the present study are higher than those from the ECCS throughout. In 50-yr-old males (height 175 cm), lower limits of normal for FEV₁ are underestimated by 198 mL, those of 50-yr-old females (height 165 cm) by 191 mL by the ECCS reference equations in comparison to the LuftiBus data. In 30-yr-old males (height 175 cm) and females (height 165 cm), lung volumes predicted by the present study's reference values are 86 and 101 mL higher than those from the ECCS, respectively. However, the difference practically vanishes at age 70 yrs, indicating that the reference values for FEV₁ provided by the ECCS equations underestimate the decline of lung volumes in elderly females.

For FVC, the present study's reference equations for the fifth percentile provide the lowest values in males aged 18–27 yrs. Lower limits of normal for FVC are underestimated by the ECCS reference equations in comparison with the LuftiBus

TABLE 5 Prediction equations for the fifth percentiles of lung function variables

Equation		R ² #
Males		
FVC L	$\exp(-10.437+2.280 \ln(H)+0.00532A-0.000124A^2)$	0.549
FEV ₁ L	$\exp(-9.111+2.014 \ln(H)+0.00102A-0.000105A^2)$	0.639
MEF ₇₅ L·s ⁻¹	$\exp(-2.524+0.812 \ln(H)+0.00661A-0.000132A^2)$	0.108
MEF ₅₀ L·s ⁻¹	$\exp(-3.338+0.911 \ln(H)-0.00289A-0.000109A^2)$	0.226
MEF ₂₅ L·s ⁻¹	$\exp(-4.262+1.009 \ln(H)-0.02485A-0.000020A^2)$	0.419
FEV ₁ /FVC %	$\exp(+6.180-0.341 \ln(H)-0.00529A+0.000026A^2)$	0.126
PEF L·s ⁻¹	$\exp(-3.992+1.170 \ln(H)+0.00493A-0.000110A^2)$	0.233
Females		
FVC L	$\exp(-9.213+2.013 \ln(H)+0.00616A-0.000155A^2)$	0.562
FEV ₁ L	$\exp(-8.521+1.865 \ln(H)+0.00357A-0.000150A^2)$	0.526
MEF ₇₅ L·s ⁻¹	$\exp(-2.977+0.867 \ln(H)+0.00698A-0.000140A^2)$	0.184
MEF ₅₀ L·s ⁻¹	$\exp(-2.374+0.674 \ln(H)+0.00330A-0.000180A^2)$	0.253
MEF ₂₅ L·s ⁻¹	$\exp(-5.140+1.145 \ln(H)-0.02002A-0.000096A^2)$	0.423
FEV ₁ /FVC %	$\exp(+5.524-0.219 \ln(H)-0.00313A+0.000004A^2)$	0.039
PEF L·s ⁻¹	$\exp(-5.032+1.316 \ln(H)+0.00767A-0.000143A^2)$	0.329

FVC: forced vital capacity; FEV₁: forced expiratory volume in one second; MEF₂₅ or 50 or 75: maximal instantaneous forced expiratory flow when 25, 50 or 75% of the FVC remains to be exhaled, respectively; PEF: peak expiratory flow; H: height (cm); A: age (yrs); exp(x): e^x. #: fraction of explained variance.

data by 210 mL in 50-yr-old males (height 175 cm) and by 270 mL in 50-yr-old females (height 165 cm). In 30-yr-old males (height 175 cm) and females (height 165 cm), lung volumes predicted by the present study's reference values are 42 and 107 mL higher than those from the ECCS, respectively. In both sexes, the decline of FVC with age is steeper than predicted by the ECCS equations.

Reference equations provided by SAPALDIA give the highest values for fifth percentiles of FEV₁ and FVC throughout, with the lower limits of NHANES III showing almost identical values. By contrast, the present study's values for the lower limit of normal for MEF₇₅ in all age groups of both sexes are highest among the reference data compared. For MEF₂₅, the present study's data indicate that the decline of late flows with age is not as steep as suggested by the ECCS and SAPALDIA.

Figure 3 illustrates the decline of FVC with age for male subjects aged 65–80 yrs compared with published reference values for elderly subjects [11, 13, 17–19]. Regarding the decline of lung volumes with age, the present data are in line with other published reference values (*i.e.* corresponding curves run almost parallel), indicating that over-reporting of stated height in elderly subjects has not occurred to a significant extent.

DISCUSSION

The present authors derived reference equations for screening spirometry from data collected in a screening programme (LuftiBus) among 8,684 healthy, never-smoking volunteers in the period 2000–2005. Fifth percentiles as lower limits of normal were derived according to a new statistical method [16].

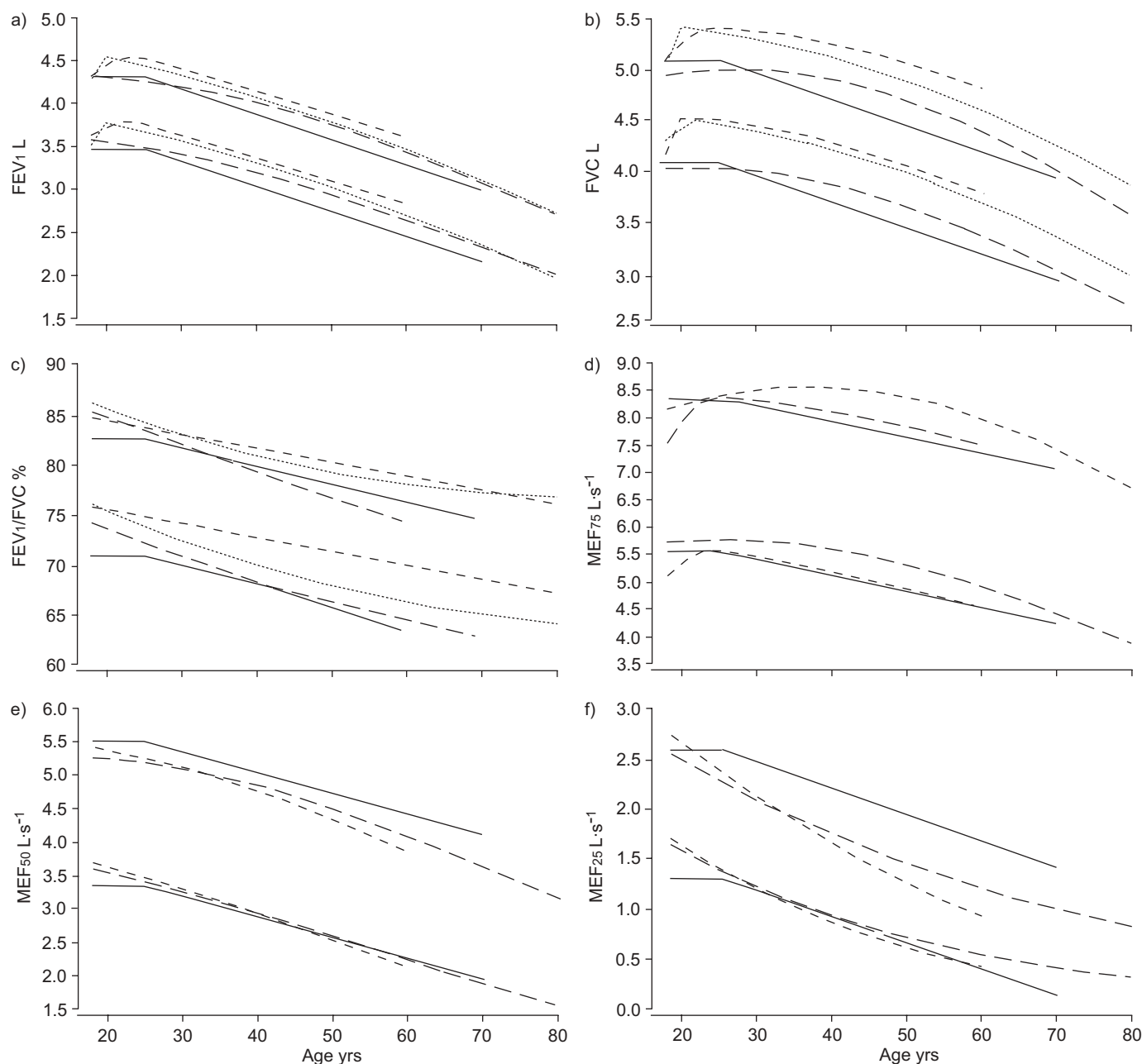


FIGURE 1. Age dependency of mean values and fifth percentiles of a) forced expiratory volume in one second (FEV₁), b) forced vital capacity (FVC), c) FEV₁/FVC, d) maximal instantaneous forced expiratory flow when 75% of the FVC remains to be exhaled (MEF₇₅), e) MEF when 50% of the FVC remains to be exhaled (MEF₅₀), and f) MEF when 25% of the FVC remains to be exhaled (MEF₂₅) in males (height 175 cm) in comparison with published reference values. —: European Community of Coal and Steel; - - - - -: Swiss Cohort Study on Air Pollution and Lung Diseases in Adults;: third National Health and Nutrition Examination Survey; - . - . - : LuftiBus.

For FVC and FEV₁, the present study's reference equations for the lower limit of normal provide values that are lower than the ones from SAPALDIA and NHANES III but higher than the ones from the ECCS in the age range 30–70 yrs. The present study's reference equations provide the lowest values in males aged 18–27 yrs for FVC only.

For both sexes, the decline of FVC in elderly subjects appears to be underestimated by the equations from the ECCS. The present study's reference values also predict a steeper decline

of FEV₁ in elderly females. By contrast, the present study's curves for the decline of MEF₂₅ with age are not as steep as the ones from the ECCS and SAPALDIA.

The present study's equations differ from those derived by the ECCS with regard to their mathematical form and to the nature of the underlying data. The ECCS reference equations were obtained by summarising published regression equations from older surveys published between the 1950s and 1980s that employed different instruments [8].

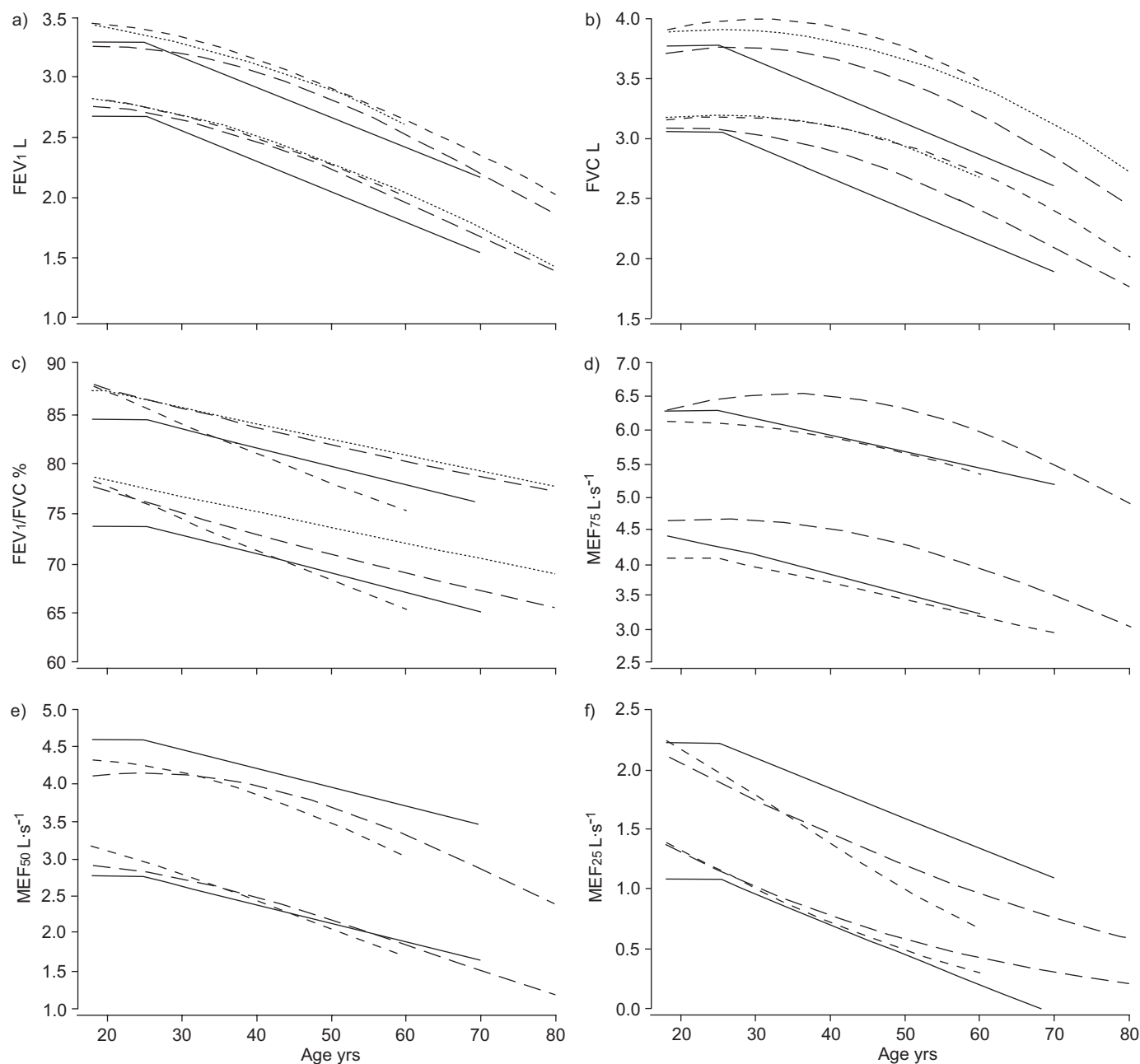


FIGURE 2. Age dependency of mean values and fifth percentiles of a) forced expiratory volume in one second (FEV₁), b) forced vital capacity (FVC), c) FEV₁/FVC, d) maximal instantaneous forced expiratory flow when 75% of the FVC remains to be exhaled (MEF₇₅), e) MEF when 50% of the FVC remains to be exhaled (MEF₅₀), and f) MEF when 25% of the FVC remains to be exhaled (MEF₂₅) in females (height 165 cm) in comparison with published reference values. —: European Community of Coal and Steel; ----: Swiss Cohort Study on Air Pollution and Lung Diseases in Adults;: third National Health and Nutrition Examination Survey; - · - ·: LuftiBus.

There are several differences in the methods applied in the SAPALDIA and the LuftiBus studies, both of which evaluated samples of the Swiss population. Subjects participating in the LuftiBus project were volunteers who were charged for the test on a nonprofit basis. In SAPALDIA, participants were randomly selected among the inhabitants of the study sites. This might result in some selection bias in the present study, despite the large population sample with a proper distribution of body height.

It has been demonstrated that using different spirometers may account for systematic deviations of lung function parameters of >5%. The systematic differences may be due to both hardware and software [22]. Thus, the systematically higher lung volumes derived by SAPALDIA could be originating from a systematic bias due to different equipment.

As proposed by the ATS, lung function tests that did not meet reproducibility criteria were not excluded from the present

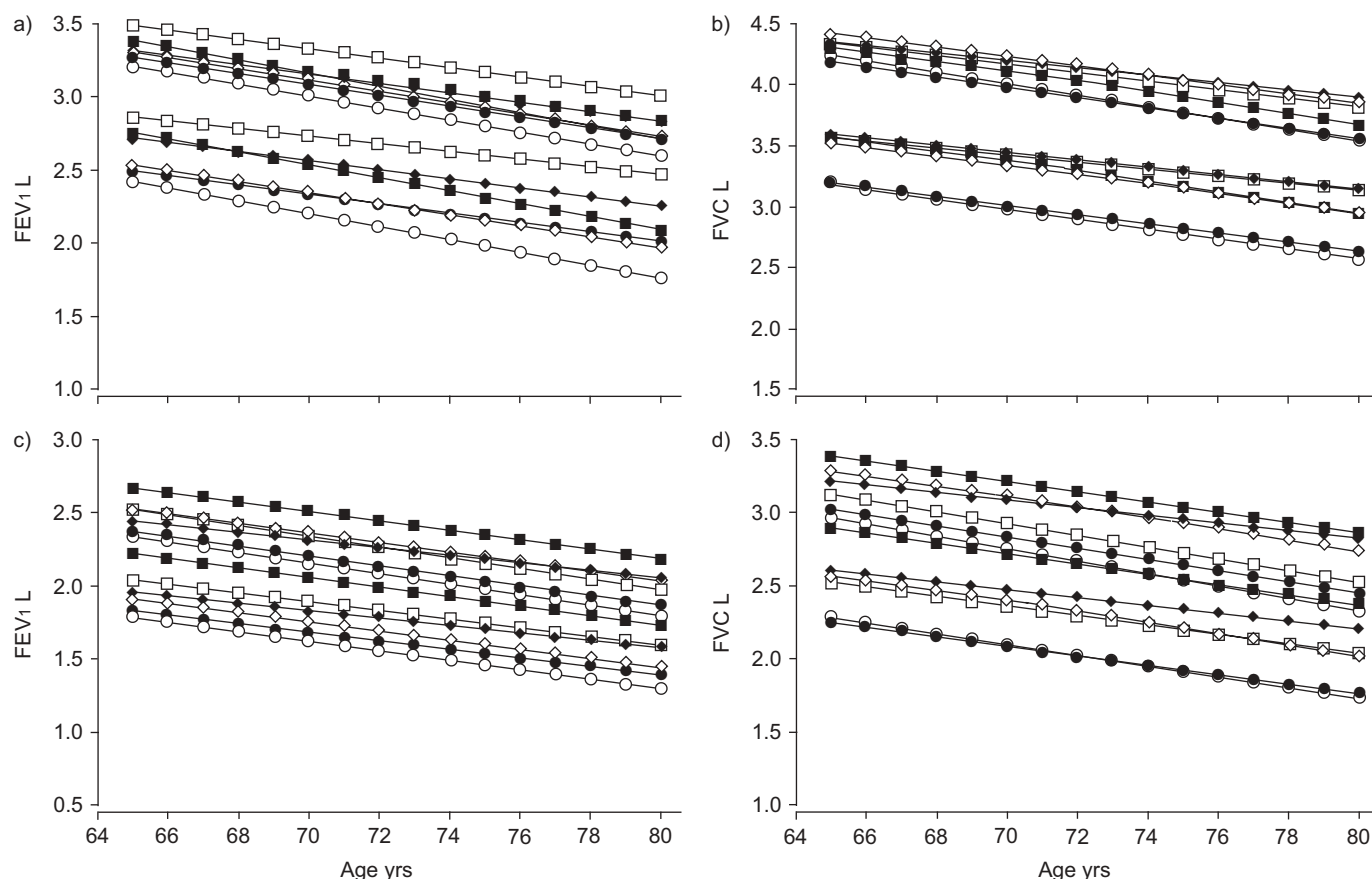


FIGURE 3. Age dependency of mean values and fifth percentiles of a) forced expiratory volume in one second (FEV₁) and b) forced vital capacity (FVC) in males (height 175 cm) and of c) FEV₁ and d) FVC in females (height 165 cm, 55 kg) aged 65–80 yrs in comparison with published reference values. ■: GARCIA-RIO *et al.* [11]; □: LANGHAMMER *et al.* [18]; ●: LUFTIBUS; ○: FALASCHETTI *et al.* [19]; ◆: McDONNELL *et al.* [13]; ◇: third National Health and Nutrition Examination Survey.

investigation [14]. In contrast, in SAPALDIA, only reproducible lung function tests results were evaluated. This probably results in systematically higher lung volumes.

Another issue could be the origin of the study population. Subjects from the present study population originate from the greater Zurich metropolitan area, whereas SAPALDIA included subjects from rural as well as from urban Swiss areas. Local exposure to traffic has been demonstrated to have adverse effects on children's lung development, which could result in lung function deficits persisting into later life [23]. This might even have resulted in differences between the lung function tests of the two different birth cohorts of the SAPALDIA and the LuftiBus project. There is evidence that pollution from fossil fuel combustion is associated with decrements in lung function, which might, in part, explain the lower values in the present study having been derived from subjects predominantly living in urban areas [24].

The present study has several limitations as data include asymptomatic never-smokers without known pulmonary disease. Moreover, no clinical or chest radiographical examinations were performed, which might result in the inclusion of some patients with unknown asymptomatic lung disease. There are limited possibilities to quantify factors that may influence lung function, such as occupational exposure,

passive smoking and the effect of chest injuries or chest surgical interventions. The nature of the evaluation did not account for all these parameters in detail. Additionally, access to medical data was not possible, except for those provided by the study subjects themselves. The current authors believe that the exclusion of subjects suffering from respiratory symptoms, such as dyspnoea (with or without exercise) or cough might have resulted in the exclusion of a large proportion of those patients. However, in this regard, the present study is in line with most other studies having published reference equations for lung function. Smoking status was quantified as "cumulative numbers of pack-yrs" and never-smokers were defined as subjects with a cumulative smoking history of <1 pack-yr. As it has been shown that a cumulative smoking history of ≤5 pack-yrs barely influences lung volumes and, due to a lack of evidence for other thresholds in the current literature, not excluding occasional cigarette smokers, pipe smokers or nontobacco smokers with a cumulative history of <1 pack-yr might be acceptable for deriving reference equations [25].

Regardless of the fact that deriving reference equations from large groups of volunteers is thought to be acceptable, provided that criteria for normal selection and proper distribution of anthropometric characteristics are satisfied, some selection bias might have crept in [10]. In particular, the

charge for the test might have kept certain groups of individuals from participating.

Using self-reported height, or estimating height from arm span is regarded as an option in the clinical setting when spirometry is performed in patients who have conditions that hamper the standing position [10]. Self-reported height was shown to give an accurate representation of true values in different populations, but age has been stated to be an important factor for misreporting height [26–30]. Height overestimation in the elderly is congruent with age-related corporal changes. The present data concerning the decline of FVC with age, however, are consistent with those from other publications that used measured height to derive reference equations for subjects aged 65–85 yrs [11, 13, 17–19].

Body mass index (BMI) has been shown to have significant effects on all the lung volumes, especially the functional residual capacity and expiratory reserve volume [31]. As a rule of thumb, lung volumes decrease as body weight increases. Thus, attempts have been made to introduce BMI as an independent variable in newly derived reference equations [32]. In a subset of the present study's subjects, the current authors assessed whether BMI could be included as a predictor of lung function. Thereby, BMI was shown not to influence lung volumes. Moreover, in analogy to height, self-reported weight was recorded in the present study. Due to a tendency of study participants to over-report height and, to a greater extent, underreport weight, stated BMI was demonstrated to be systematically underestimated in various studies [28, 33]. Thus, the current authors believe that using self-reported BMI is of limited value for deriving reference equations.

As stated in the 1994 update of the ATS guidelines for standardisation of spirometry [14], nose-clips do not appreciably influence the FVC when using the open-circuit technique. However, their use was encouraged, especially when performing a slow vital capacity manoeuvre, because some people breathe through the nose. The use of nose-clips was considered mandatory if a closed-circuit technique with carbon dioxide absorption was used. Guidelines from 2005 [34], published at the end of data collection for the LuftiBus study, recommend the use of a nose-clip or manual occlusion of the nares. It has been demonstrated that the application of a nose-clip has no significant impact on measurement of peak expiratory flow, but its importance for the other lung function parameters, to the present authors' knowledge, has not been studied [35]. That the present study's lung function tests were performed without a nose-clip might, nevertheless, partly explain the observed differences with the SAPALDIA reference equations, since a certain loss of air through the nasal route is likely to have occurred at least in some subjects.

It was proposed that reference equations should be derived from a population most similar to that for which the equations are to be used and based on measurements obtained by the same instruments and testing procedures [32]. Since the methodology used in the LuftiBus project mirrors the methods used in daily practice, where measurement of height and application of a nose-clip is often abandoned, the present results may thus provide a valuable contribution to lung function testing within a routine outpatient setting. The

present study in particular meets the major need for updated and empirically derived reference equations of forced spirometry for subjects aged 65–80 yrs.

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