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References values for forced spirometry

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Reference values for forced spirometry. J. Roca, F. Burgos, J. Sunyer, M. Saez, S. Chinn, J.M. Antó, R. Rodríguez-Roisin, PhH. Quanjer, D. Nowak, P. Burney, for the Group of the European Community Respiratory Health Survey. ©ERS Journals Ltd 1998.

ABSTRACT: The European Coal and Steel Community (ECSC) prediction equations exemplify a significant effort carried out approximately 15 yrs ago to provide uniform standards for lung function testing, but this set of equations has not been properly validated as yet. The present study evaluates the ECSC reference values and four other sets of prediction equations, using spirometric data collected in 12,900 nonasthmatic subjects (43% lifetime nonsmokers and 36% active smokers) aged 20–44 yrs from the European Community Respiratory Health Survey (ECRHS).

Standardized spirometric measurements were obtained using a common protocol in 34 centres in 14 countries. For each prediction equation, the prediction deviations (*i.e.* observed minus predicted value) for forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were examined for the whole study population and for each centre.

For the age range included, the errors about the ECSC equations showed the most prominent underestimation of both predicted FVC (+355 and +360 mL on average in males and females, respectively) and predicted FEV_1 (+211 and +200 mL, respectively) among the five studies examined. As expected, FVC and FEV_1 in active smokers from the ECRHS were significantly lower than in lifetime nonsmokers (each $p<0.01$).

We conclude that the present European recommendations on lung function reference values should be reconsidered, but further data for nonsymptomatic subjects above the age of 44 yrs are needed.

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Selected sets of reference values for forced spirometry derived from nonsmoking, white subjects [1] show marked differences among studies [2–6] in both predicted forced vital capacity (FVC) (up to 640 mL) and predicted forced expiratory volume during the first second (FEV_1) (up to 310 mL). The magnitude of the differences among reference values gives rise to potential concerns for the clinical assessment of ventilatory capacity. Moreover, it has been suggested recently in a preliminary study that the European Coal and Steel Community (ECSC) prediction equations [2, 7] significantly underestimate predicted FVC and predicted FEV_1 [8, 9].

The main goal of the present study was to evaluate five sets of prediction equations for forced spirometry: the ECSC predicted values [2, 7] and those reported by four other authors [3, 4, 10, 11], using standardized spirometric measurements from 12,900 nonasthmatic subjects aged 20–44 yrs pertaining to the European Community Respiratory Health Survey (ECRHS). The four sets of prediction equations, (Knudson *et al.* [10], Paoletti *et al.* [4], Crapo *et al.* [11], and Roca *et al.* [3]), examined in addition to the ECSC reference values, were selected in the present study among those included in [1] because they had followed current standards for forced spirometry [2, 12].

The ECRHS is a multicentre study of the variation in the prevalence, risk factors and management of asthma throughout the European Union and elsewhere [13], and includes standardized measurements of forced spirometry collected using a common protocol in 34 centres in 14 countries.

Methods

Subjects

The protocol for the ECRHS has been described elsewhere [13–15]. In brief, participating centres selected an area defined by pre-existing administrative boundaries, with a population of at least 150,000 individuals. Where possible, an up-to-date sampling frame was used to select randomly at least 1,500 males and 1,500 females, aged 20–44 yrs. In stage I, subjects were sent a questionnaire enquiring about respiratory symptoms and attacks of asthma over the last 12 months, current use of asthma medication and nasal allergies, including hay fever. A random sample of subjects was selected to take part in stage II. Those who had already responded to stage I were invited to answer a more detailed administered questionnaire, and to take part in blood tests, skin tests, assessment of lung function by spirometry and airway challenge with methacholine. The questionnaire collected information on health status, current smoking and smoking history.

Of 43 centres participating in stage II, data from 34 centres in 14 countries was included. Five centres had not fully checked and edited their data, and others supplied data after the deadline for this analysis, but the response to stage II varied from 12.2% (Montpellier, France) to 90.3% (Umeå, Sweden) of those selected. The overall response rate for stage II of the areas included in the present study was 48.1%. Among the 16,689 subjects participating in stage II, 12,900 were included in the present analysis. Subjects who reported asthma-related symptoms were excluded. In the ECRHS, a subject with asthma-related symptoms was defined as one who reported any of the following three conditions: 1) being woken up by an attack of shortness of breath at any time over the last 12 months; 2) having an attack of asthma during the last 12 months; and 3) currently taking any medicine for asthma (including inhalers, aerosols or tablets). Consequently, the present study did not exclude past or present smokers, or subjects with current or previous respiratory disease other than asthma or any condition that may affect ventilatory function.

Spirometric measurements and quality control

Standardization of forced spirometry is described in detail in the protocol [14]. In brief, baseline FVC and FEV_1 were measured in all subjects who agreed to these tests. Subjects were permitted nine attempts to provide at least two technically acceptable manoeuvres. All of the techni-

Table 1. – Main characteristics of the studies on reference values for forced spirometry

	Study sample				
	ECSC [2, 7]	KNUDSON *et al.* [10]	PAOLETTI *et al.* [4]	CRAPO *et al.* [11]	ROCA *et al.* [3]
	Summary equations obtained from different studies as reported in Ref. [2]	Randomly selected sample from the general population of the area	Randomly selected sample from the general population of the area	Selected volunteer*	Selected volunteers
Country	–	Arizona (USA)	Italy	Utah (USA)	Spain
Altitude	–	SL	SL	1400 m	SL
Age yrs	–	20–85 (males) 20–88 (females)	29–64 (males) 21–64 (females)	15–84	20–70
Smokers	–	No	No	No	No
Males	–	86	59	126	443
Females	–	204	313	125	427
Body position	–	Sitting	Sitting	Sitting	Sitting
Equipment	–	Pneumotachograph	Fleisch No. 3 pneumotach HP47804 System	Water-sealed 13.5 L metal bell spirometer	Fleisch No. 3 pneumotach HP47804 HP Vertek System
Calculations					
Beginning of test	–	Back-extrapolation	Back-extrapolation	Back-extrapolation	Back-extrapolation**
End of test	–	Flow <50 mL·s⁻¹	Flow <15 mL·s⁻¹	Flow <50 mL·s⁻¹	Flow <15 mL·s⁻¹

European Coal and Steel Community (ECSC) (Ref. [2], Chap. 7, pp. 45–51) provides detailed information about the items indicated in the table. SL: sea level or close to sea level. *: members of the Church of Jesus Christ of Latter-Day Saints. **: modified forced expiratory volume in one second (FEV_1) prediction equation [3].

Table 2. – Prediction equations examined in the present study

	FVC L (males)			FVC L (females)		
	Equation	r^2	RSD	Equation	r^2	RSD
ECSC [7]	0.0576H - 0.0260A - 4.340	NA	0.61	0.0443H - 0.0260A - 2.890	NA	0.43
KNUDSON *et al.* [10]	0.0844H - 0.0298A - 8.782	0.72	0.64	0.0444H - 0.0169A - 3.195	0.49	0.48
PAOLETTI *et al.* [4]	0.0724H - 0.0273A - 6.382	0.48	0.58	0.0412H - 0.0154A - 2.329	0.38	0.39
CRAPO *et al.* [11]	0.0600H - 0.0214A - 4.650	0.53	0.64	0.0491H - 0.0216A - 3.590	0.74	0.39
ROCA *et al.* [3]	0.0678H - 0.0147A - 6.055	0.52	0.53	0.0454H - 0.0211A - 2.825	0.56	0.40
	FEV_1 L (males)			FEV_1 L (females)		
	Equation	r^2	RSD	Equation	r^2	RSD
ECCS [7]	0.0430H - 0.0290A - 2.490	NA	0.51	0.0395H - 0.025A - 2.600	NA	0.38
KNUDSON *et al.* [10]	0.0665H - 0.0292A - 6.515	0.74	0.52	0.0665H - 0.0292A - 6.515	0.74	0.52
PAOLETTI *et al.* [4]	0.0494H - 0.0275A - 3.576	0.35	0.48	0.0243H - 0.0196A - 0.282	0.48	0.29
CRAPO *et al.* [11]	0.0414H - 0.0244A - 2.190	0.64	0.49	0.0342H - 0.0255A - 1.578	0.79	0.33
ROCA *et al.* [3]	0.0514H - 0.0216A - 3.955	0.56	0.45	0.0326H - 0.0253A - 1.286	0.67	0.32

ECSC: European Coal and Steel Community. FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; H: height (cm); A: age (yrs); r^2: squared multiple correlation coefficient; RSD: residual standard deviation; NA: not available.

cians involved in the study, irrespective of their previous background, received identical training. At the start of the ECRHS, a quality-control visit to each laboratory was carried out, either by the personnel of the Coordinating Centre (London) or by two investigators of the ECRHS in the corresponding country to examine all of the procedures involved in the protocol. They specifically checked the volume signal of the equipment using a 3 L calibrated syringe and examined the equipment for leaks. The equipment used in each centre is reported in the Appendix. During the study, technicians were instructed to verify the volume signal of the equipment on a daily basis using calibrated syringes (2 or 3 L).

Reference equations

The main characteristics of the five sets of reference equations examined in this study are shown in tables 1 and 2 [3, 4, 10, 11]. The ECSC equations [2, 7] were derived from data from different studies carried out before the 1980s using different methods and from differing populations, as reported in [2]. The remaining four studies were derived following modern standards [2, 12] and they were reported throughout the 1980s. Prediction equations for FEV_1 by ROCA *et al.* [3] in the present study were corrected to back-extrapolation following the calculations reported in [3].

Data analysis

Predicted values for FVC and FEV_1 were computed for each of the equations. One-way analysis of variance (ANOVA) was carried out, where the prediction deviations (*i.e.* observed minus predicted value) were the dependent variables and centres the factor variable. The confidence interval of the mean prediction deviations was calculated for each centre using the standard deviation observed in that centre rather than that of the whole population. In a second step, a two-way ANOVA, including centres and smoking, was carried out to control for the effects of smoking on the prediction deviations by centres. Modification of the effects of smoking by age was assessed in the same model with the interaction of age and smoking. The variable smoking was analysed as: active 1 smokers, exsmokers and lifetime nonsmokers. A p-value of <0.05 was considered statistically significant.

Mean values of prediction deviations for each of the five sets of prediction equations were examined and compared with the corresponding standardized prediction deviations (*i.e.* mean prediction deviation/RSD). RSD is the residual standard deviation of the corresponding prediction equation.

Results

Anthropometric and lung function data of the 12,900 subjects included in the present study are set out in table 3. The mean and 95% confidence interval (95% CI) of the prediction deviations in each centre for each of the five sets of reference equations are illustrated in figures 1–4 for FVC (males), FVC (females), FEV_1 (males), and FEV_1 (females), respectively. Results for each centre and country are reported in the Appendix. In figures 1–4, the horizontal dashed lines indicate a lack of difference between observed and predicted values. Accordingly, those centres whose 95% CI did not intercept with the corresponding horizontal dashed line showed a statistically significant difference between observed and predicted values.

Table 3. – Anthropometric and lung function data

	Males	Females
Subjects n	6479	6419
Active smokers %	39	33
Exsmokers %	21	21
Lifetime nonsmokers %	40	46
Age yrs	33±7.0	33±7.0
Height cm	177±7	164±6
Weight kg	78±12	63±11
FVC L	5.37±0.83	3.87±0.58
FEV_1 L	4.39±0.69	3.25±0.50
FEV_1/FVC %	82±7	84±6
PEFR $L \cdot s^{-1}$	9.96±2.04	6.86±1.37

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; PEFR: peak expiratory flow rate. Results are expressed as mean±SD.

The ECSC equations underpredicted FVC and FEV_1 in both males and females. The mean of the prediction deviations for FVC in all the centres was +355 mL in males and +360 mL in females. Only one centre (Montpellier, France) in males and two centres (Albacete, Spain and Bergen, Norway) in females displayed significantly lower observed than predicted FVC values. The mean of the prediction deviations for FEV_1 was +211 mL in males and +200 mL in females. Similarly, only two centres (Albacete, Spain and Bergen, Norway) showed negative prediction deviations in males and only two centres (Bordeaux, France and Bergen, Norway) in females.

Predicted values by KNUDSON *et al.* [10] in females displayed a picture very similar to that seen in the ECSC equations. The mean of the prediction deviations was +340 mL for FVC and +250 mL for FEV_1. In males, KNUDSON *et al.* [10] also underpredicted FVC and FEV_1, but the magnitude of the prediction deviations (+170 mL and +70 mL, respectively) was smaller than in females. PAOLETTI *et al.* [4] overestimated FVC particularly in ma-les (21 centres, 62%, showed significantly lower observed than predicted values and only one centre displayed a positive mean of prediction deviations in this variable). The mean of the prediction deviations for FVC in all of the centres was -190 mL in males and -50 mL in females. In contrast, PAOLETTI *et al.* [4] underpredicted FEV_1 in both sexes. The mean of the prediction deviations was +112 mL and + 200 mL, respectively. Up to 24 centres (71%) in males and 30 centres (88%) in females showed higher observed than predicted FEV_1. Accordingly, predicted values for the FEV_1/FVC ratio by these authors [4], 77% for males and 78% for females, were significantly lower than the actual FEV_1/FVC ratio from the ECRHS, as indicated in table 3.

Observed and predicted FEV_1 were closer both in CRAPO *et al.* [11] (mean of the prediction errors: +45 mL in males and +60 mL in females) and in ROCA *et al.* [3] (-57 mL in males and +30 mL in females) than in the other sets of reference equations analysed [4, 10, 11]. However,

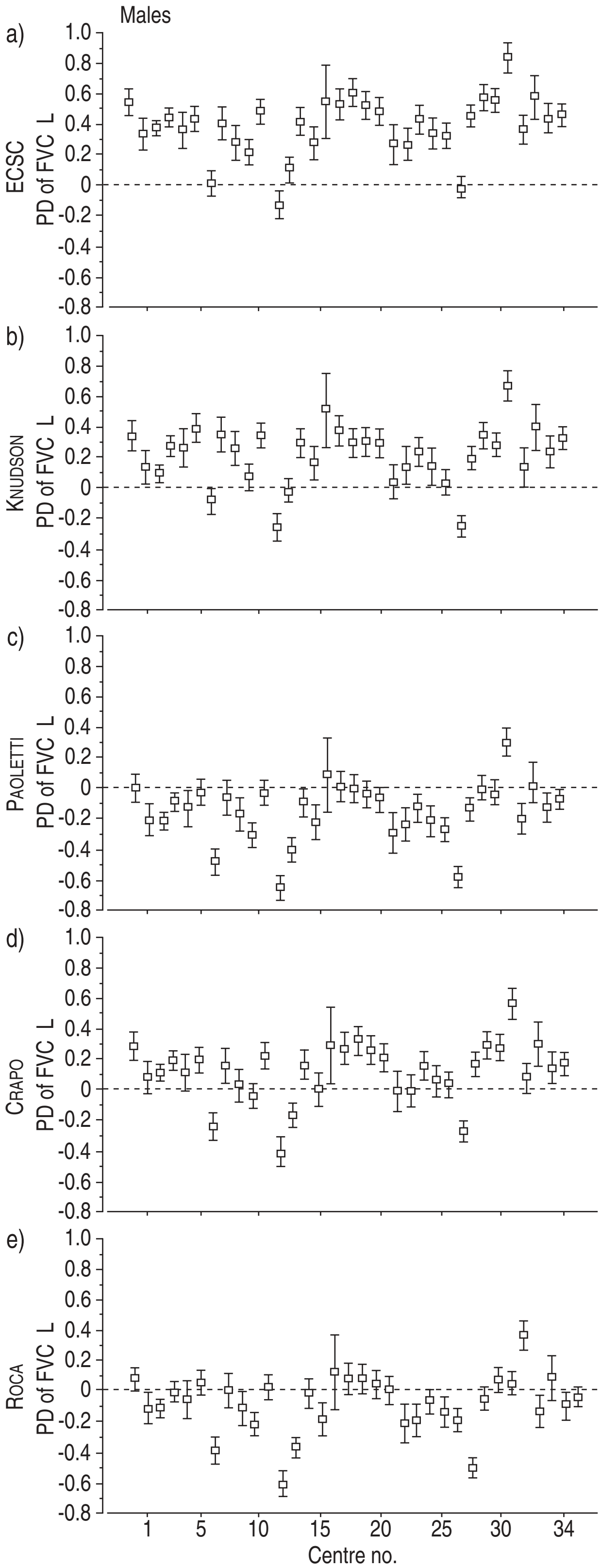

Fig. 1. – The symbols correspond to mean±95% confidence intervals of the prediction deviations (PD) (observed-predicted value) in each centre for forced vital capacity (FVC) in males. From the studies of a) European Coal and Steel Community (ECSC) [2, 7]; b) KNUDSON *et al.* [10]; c) PAOLETTI *et al.* [4]; d) CRAPO *et al.* [11]; and e) ROCA *et al.* [3]. Identification of centres and countries and numerical data for each centre following the same order are given in the Appendix.

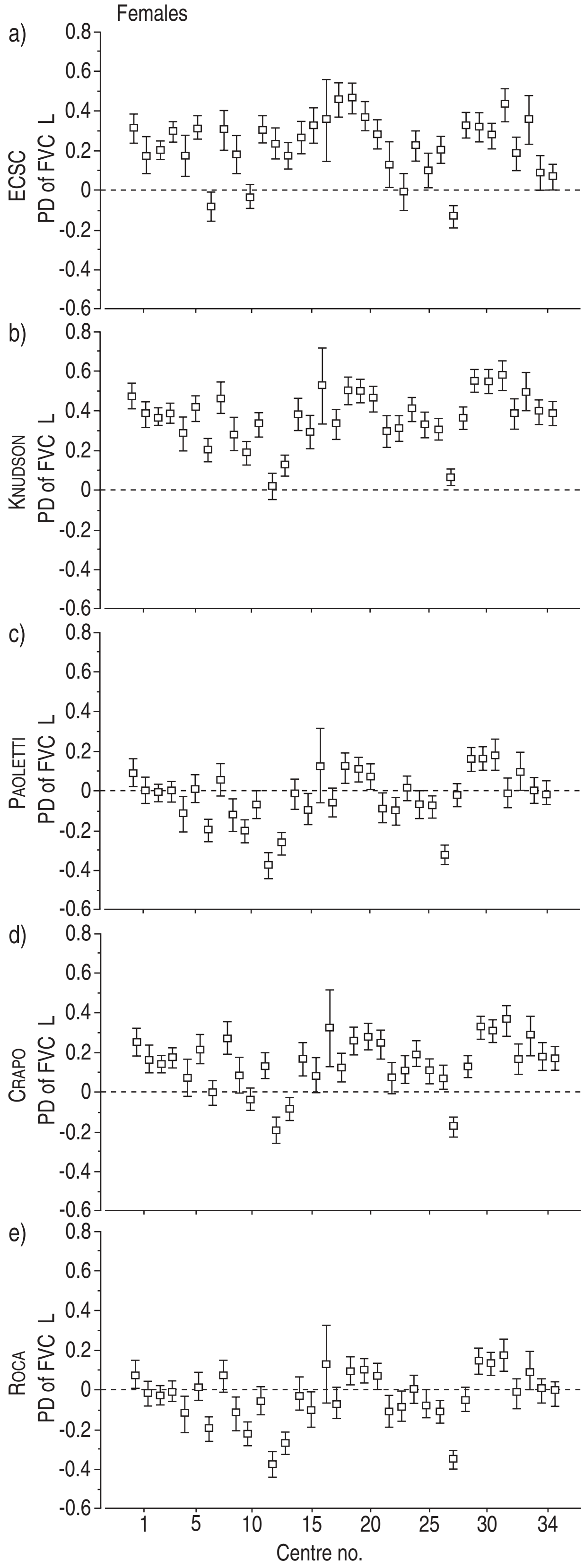

Fig. 2. – Mean±95% confidence intervals of the prediction deviations (PD) in each centre for forced vital capacity (FVC) in females. From the studies of a) European Coal and Steel Community (ECSC) [2, 7]; b) KNUDSON *et al.* [10]; c) PAOLETTI *et al.* [4]; d) CRAPO *et al.* [11]; and e) ROCA *et al.* [3]. See legend to figure 1 for further information.

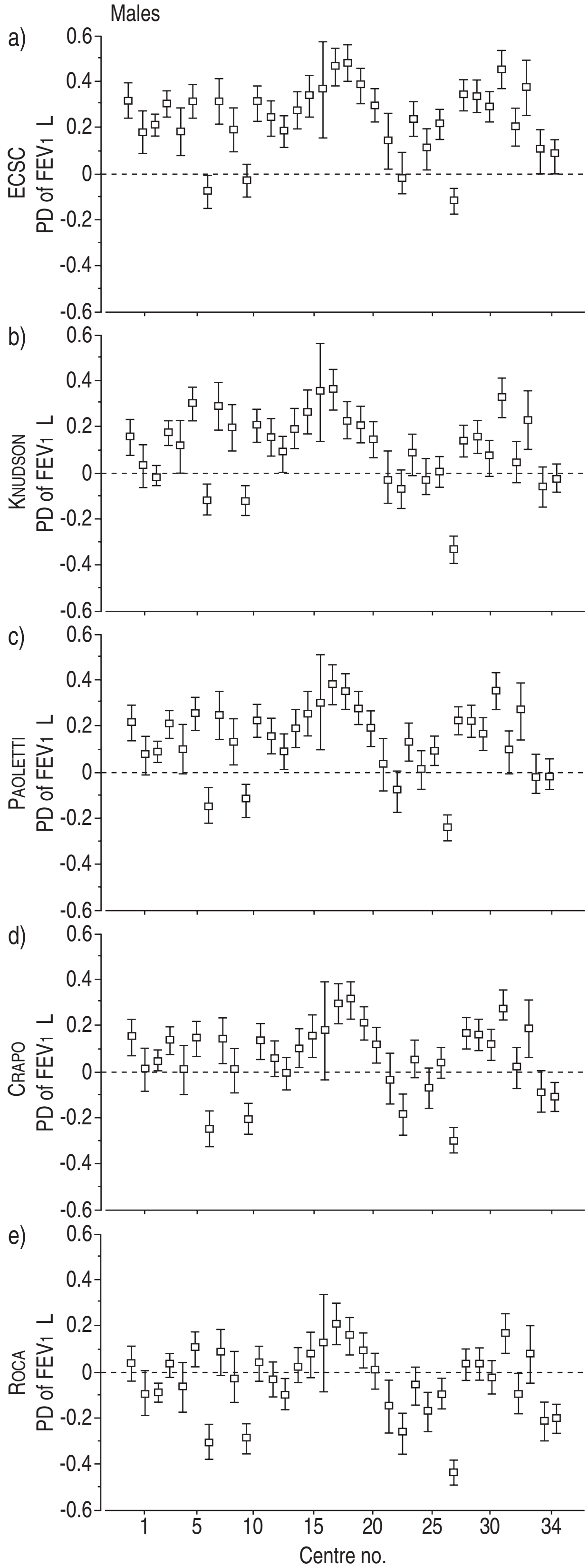

Fig. 3. – Mean±95% confidence intervals of the prediction deviations (PD) in each centre for the forced expiratory volume in one second (FEV_1) in males. From the studies of a) European Coal and Steel Community (ECSC) [2, 7]; b) KNUDSON *et al.* [10]; c) PAOLETTI *et al.* [4]; d) CRAPO *et al.* [11]; and e) ROCA *et al.* [3]. See legend to figure 1 for further information.

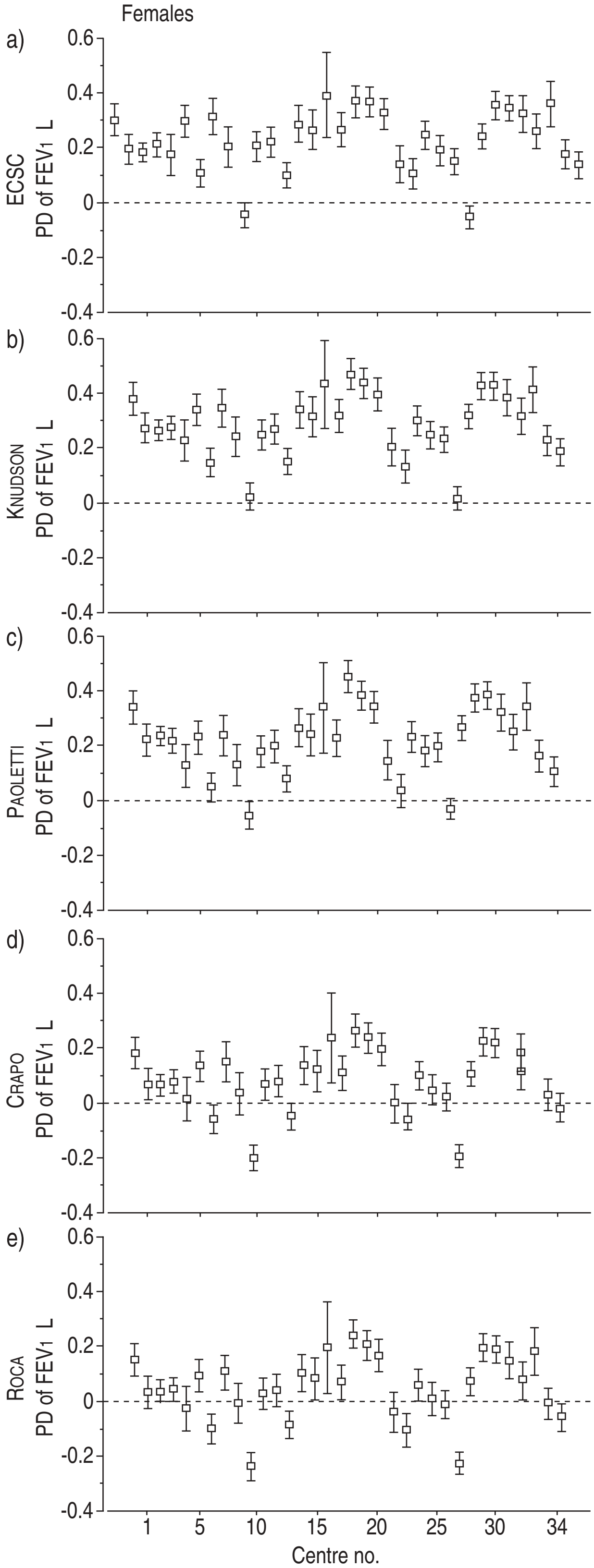

Fig. 4. – Mean±95% confidence intervals of the prediction deviations (PD) in each centre for the forced expiratory volume in one second (FEV_1) in females. From the studies of a) European Coal and Steel Community (ECSC) [2, 7]; b) KNUDSON *et al.* [10]; c) PAOLETTI *et al.* [4]; d) CRAPO *et al.* [11]; and e) ROCA *et al.* [3]. See legend to figure 1 for further information.

Table 4. – Prediction deviations in active smokers and lifetime nonsmokers

	FVC mL		FEV_1 mL	
	Active smokers (2525 M/2120 F)	Lifetime nonsmokers (2590 M/2956 F)	Active smokers	Lifetime nonsmokers
ECSC [7]				
M	284±636	376±636	123±540	260±533
F	315±480	341±475	139±406	204±388
KNUDSON *et al.* [10]				
M	113±647	159±645	0±556	101±543
F	309±471	336±464	201±406	265±387
PAOLETTI *et al.* [4]				
M	-248±634	-180±632	29±540	158±529
F	-79±472	-53±465	143±414	204±397
CRAPO *et al.* [11]				
M	18±634	114±630	-46±543	101±533
F	84±474	112±467	4±406	67±389
ROCA *et al.* [3]				
M	-177±634	-81±623	-141±544	4±528
F	-89±474	-62±467	-32±407	31±390

European Coal and Steel Community. FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; M: males; F: females. Results are expressed as mean±SD. Exsmokers (1,360 males and 1,349 females) are not included in the table.

CRAPO *et al.* [11] moderately underpredicted FVC (20 centres, 59%, in males and 24 centres, 71%, in females showed significant positive prediction errors). The mean of the prediction deviations was +88 mL in males and +120 mL in females. In contrast, ROCA *et al.* [3] slightly overpredicted FVC (15 centres, 44%, in males and 13 centres, 38%, in females showed significant negative prediction errors). The mean of the prediction deviations being -120 mL in males and -60 mL in females.

The geographical distribution of the prediction deviations between the different centres and countries (figs. 1–4 and Appendix) did not show any particular pattern. Moreover, the overall dispersion (table 4) of the prediction deviation was similar for the five sets of equations examined. Analysis of the standardized prediction deviations did not change the overall picture given in the present study.

Prediction deviations in active smokers and lifetime nonsmokers are shown in table 4. The distribution of prediction deviations by centres depicted in figs. 1–4 was preserved after adjusting for the effects of tobacco. It is worth noting that the magnitude of the prediction deviations in lifetime nonsmokers by ROCA *et al.* [3] was negligible for FEV_1 (100% and 101% predicted in males and females, respectively), and only slightly higher for FVC (99% and 98% pred, respectively).

Active smokers showed a significantly lower FVC and FEV_1 than lifetime nonsmokers (each $p<0.01$). As expected, the deleterious effect of tobacco smoking on lung function was more evident in males than in females and, in both sexes, it was more marked in FEV_1 than in FVC. The effects of smoking on lung function varied with age, but because of the limited age range examined in the present study, the interactions between smoking and age were not analysed further.

Discussion

The present study indicates that FVC and FEV_1 measured in 12,900 subjects from the ECRHS in 34 centres in 14 countries were markedly higher than the predicted values estimated by both the ECSC equations [7] and KNUDSON *et al.* [10], (figs. 1–4), in the age interval examined. Predicted values by PAOLETTI *et al.* [4] showed a moderate overestimation of FVC together with an underestimation of FEV_1. Predicted values by CRAPO *et al.* [11] and ROCA *et al.* [3] were the closest among those examined in the present study and both groups showed a reasonable agreement with the forced spirometric measurements carried out in the ECRHS. Moreover, from the results of PISTELLI *et al.* [16] it can be presumed that the differences in predicted FVC between CRAPO *et al.* [11] and ROCA *et al.* [3] could be reduced further (by 70 mL on average) if the FVC equations by CRAPO *et al.* [11] were corrected following the current end-of-test recommendations [7, 17]. The confirmation of a significant deleterious effect of active tobacco smoking on lung function in these relatively young subjects (tables 3 and 4) is the third piece of information provided by the present study.

The characteristics of the age interval analysed in the present study (young subjects from 20–44 yrs) preclude the use of lung function measurements from the ECRHS to generate new prediction equations for forced spirometry and may restrict the extrapolations based on age-adjusted analyses. The lack of information above the age of 44 yrs does not allow one to test for linearity of the decline in lung function with age, as it has been suggested by different studies [1, 18, 19].

Discrepancies observed among the five sets of prediction equations [2–4, 10, 11] examined in the present study can be explained by various methodological factors influencing spirometric measurements [1, 18]. Among them, technical factors (equipment, technicians, *etc.*) are more likely to play a principal role. The contribution of a cohort effect, however, cannot be excluded since the largest differences were observed in the earlier studies [2, 7, 10]. By contrast, potential ethnic differences between northern and southern European countries and the different methods used to select the reference sample (table 2) do not seem to be key factors in explaining the discrepancies among sets of prediction equations. A detailed review of the factors explaining why ECSC [2, 7] equations and KNUDSON

Appendix 1. – Characteristics of the study population (males and females) by city and country

Centre	Code	City	Country	Age yrs	Height m	Subjects n	Nonsmokers n (%)	Exsmokers n (%)	Current smokers n (%)	Equipment
Males										
1	10	Antwerp-South	B	32	1.79	181	88 (49)	34 (19)	59 (32)	Sensor Medics 2130
2	12	Antwerp-City		32	1.78	127	38 (30)	26 (20)	63 (50)	Sensor Medics 2130
3	31	Hamburg	D	32	1.81	505	152 (30)	127 (25)	226 (45)	Jaeger Pneumolab
4	33	Erfurt		32	1.77	351	109 (31)	72 (21)	170 (48)	Jaeger Pneumolab
5	50	Barcelona	E	32	1.74	98	30 (31)	20 (20)	48 (49)	Biomedin
6	51	Galdakao		31	1.72	203	60 (30)	27 (13)	116 (57)	Biomedin
7	53	Albacete		30	1.73	182	45 (25)	26 (14)	111 (61)	Biomedin
8	54	Oviedo		33	1.72	115	28 (24)	12 (11)	75 (65)	Biomedin
9	55	Huelva		32	1.71	113	35 (31)	10 (9)	68 (60)	Biomedin
10	60	Bordeaux	F	31	1.76	227	83 (36)	52 (23)	92 (41)	Vitalograph
11	61	Grenoble		34	1.76	229	88 (38)	55 (24)	86 (38)	Biomedin
12	62	Montpellier		35	1.75	190	84 (44)	45 (24)	61 (32)	Biomedin
13	64	Paris		35	1.76	261	87 (33)	72 (28)	102 (39)	Biomedin
14	70	Dublin	IR	32	1.75	146	60 (42)	27 (18)	59 (40)	Biomedin
15	80	Pavia	I	34	1.75	125	42 (34)	16 (13)	67 (53)	Biomedin
16	81	Turin		33	1.72	95	49 (52)	20 (20)	26 (28)	Biomedin
17	83	Verona		32	1.76	147	54 (36)	36 (25)	57 (39)	Biomedin
18	90	Groningen	NL	34	1.82	171	57 (33)	24 (14)	90 (53)	Morgan Spirograph DS12
19	91	Bergen-op-Zoom		33	1.79	189	72 (38)	39 (21)	78 (41)	Morgan Spirograph DS12
20	92	Geleen		33	1.78	178	68 (38)	47 (26)	63 (36)	Morgan Spirograph DS12
21	110	Cambridge	UK	33	1.78	79	51 (64)	15 (19)	13 (17)	Biomedin
22	111	Cardiff		34	1.74	136	60 (44)	26 (19)	50 (37)	Biomedin
23	113	Ipswich		34	1.78	164	76 (46)	39 (24)	49 (30)	Biomedin
24	115	Norwich		33	1.77	148	65 (44)	43 (29)	40 (27)	Biomedin
25	130	Reykjavik	IC	33	1.81	246	79 (32)	61 (25)	106 (43)	Sensor Medics 2450
26	140	Bergen	N	33	1.81	355	153 (43)	48 (14)	154 (43)	Sensor Medics Pne 12050
27	150	Göteborg	S	33	1.80	256	120 (47)	49 (19)	87 (34)	Sensor Medics 922
28	151	Umeå		33	1.79	214	111 (52)	60 (28)	43 (20)	Sensor Medics 922
29	152	Uppsala		32	1.81	245	130 (53)	55 (22)	60 (25)	Sensor Medics 922
30	180	Wellington	NZ	34	1.77	161	91 (56)	32 (20)	38 (24)	Sensor Medics 2130
31	182	Christchurch		33	1.78	153	84 (55)	43 (28)	26 (17)	Ohio 840
32	183	Hawkes-Bay		34	1.77	78	41 (53)	20 (26)	17 (21)	Sensor Medics S4049
33	191	Portland	USA	35	1.79	148	85 (58)	29 (19)	34 (23)	Spirotech S500
34	220	Melbourne	AUS	34	1.76	259	127 (49)	57 (22)	75 (29)	Hewlett Packard
Females										
1	10	Antwerp-South	B	33	1.66	165	72 (44)	53 (32)	40 (24)	Sensor Medics 2130
2	12	Antwerp-City		32	1.65	171	70 (41)	40 (23)	61 (36)	Sensor Medics 2130
3	31	Hamburg	D	33	1.68	440	159 (36)	101 (23)	180 (41)	Jaeger Pneumolab
4	33	Erfurt		33	1.64	308	136 (44)	65 (21)	107 (35)	Jaeger Pneumolab
5	50	Barcelona	E	32	1.60	97	33 (34)	20 (21)	44 (45)	Biomedin
6	51	Galdakao		31	1.59	167	67 (40)	25 (15)	75 (45)	Biomedin
7	53	Albacete		32	1.60	210	91 (44)	25 (12)	94 (44)	Biomedin
8	54	Oviedo		32	1.59	114	43 (38)	12 (10)	59 (52)	Biomedin
9	55	Huelva		32	1.59	105	45 (43)	11 (10)	49 (47)	Biomedin
10	60	Bordeaux	F	31	1.63	216	79 (37)	44 (20)	94 (43)	Vitalograph
11	61	Grenoble		35	1.63	194	90 (48)	58 (30)	42 (22)	Biomedin
12	62	Montpellier		34	1.63	199	102 (51)	46 (23)	51 (26)	Biomedin
13	64	Paris		34	1.64	286	120 (42)	72 (25)	94 (33)	Biomedin
14	70	Dublin	IR	32	1.63	119	50 (42)	17 (14)	52 (44)	Biomedin
15	80	Pavia	I	34	1.62	110	54 (49)	21 (19)	35 (32)	Biomedin
16	81	Turin		32	1.61	92	48 (53)	13 (14)	31 (33)	Biomedin
17	83	Verona		32	1.61	152	81 (53)	27 (18)	44 (29)	Biomedin
18	90	Groningen	NL	33	1.69	170	75 (44)	30 (17)	65 (39)	Morgan Spirograph DS12
19	91	Bergen-op-Zoom		33	1.65	207	74 (35)	61 (30)	72 (35)	Morgan Spirograph DS12
20	92	Geleen		34	1.65	169	64 (38)	36 (21)	69 (41)	Morgan Spirograph DS12
21	110	Cambridge	UK	33	1.65	112	66 (59)	18 (16)	28 (25)	Biomedin
22	111	Cardiff		34	1.61	177	98 (57)	25 (14)	51 (29)	Biomedin
23	113	Ipswich		32	1.63	184	110 (60)	30 (16)	44 (24)	Biomedin
24	115	Norwich		33	1.64	183	109 (59)	39 (22)	34 (19)	Biomedin
25	130	Reykjavik	IC	32	1.67	245	103 (42)	53 (22)	89 (36)	Sensor Medics 2450
26	140	Bergen	N	32	1.66	351	138 (39)	64 (18)	149 (43)	Sensor Medics Pne 12050
27	150	Göteborg	S	32	1.66	275	108 (39)	63 (23)	104 (38)	Sensor Medics 922
28	151	Umeå		33	1.66	215	108 (50)	40 (19)	67 (31)	Sensor Medics 922
29	152	Uppsala		33	1.66	235	117 (50)	53 (23)	63 (27)	Sensor Medics 922
30	180	Wellington	NZ	33	1.64	127	70 (56)	39 (30)	18 (14)	Sensor Medics 2130
31	182	Christchurch		33	1.64	141	78 (54)	29 (20)	36 (26)	Ohio 840
32	183	Hawkes-Bay		33	1.63	84	50 (60)	18 (21)	16 (19)	Sensor Medics S4049
33	191	Portland	USA	34	1.64	175	108 (62)	41 (23)	26 (15)	Spirotech S500
34	220	Melbourne	AUS	34	1.63	230	125 (54)	51 (22)	54 (24)	Hewlett Packard

Centres are displayed in the same order as in figures 1–4. Code: European Community Respiratory Health Survey Code; B: Belgium; D: Germany; E: Spain; F: France; IR: Ireland; I: Italy; NL: The Netherlands; UK: United Kingdom; IC: Iceland; N: Norway; S: Sweden; NZ: New Zealand; USA: United States of America; AUS: Australia.

et al. [10] underpredicted FVC and FEV_1, and why the FEV_1/FVC ratio is underpredicted by PAOLETTI *et al.* [4] was, however, beyond the scope of this study. Table 4 suggests that an even more marked underprediction of FVC and FEV_1 by both ECSC [1, 7] and KNUDSON *et al.* [10] should be expected if the study had been constrained to the ECRHS subjects, *i.e.* lifetime nonsmokers who were highly screened for health status.

The standardized prediction deviation for a given prediction equation is a dimensionless index that indicates how far the mean observed lung function value for FVC (or FEV_1) in the ECRHS is removed from the predicted value. Since the calculation of the standardized prediction deviation involves a correction by the RSD of the corresponding prediction equation, this index seems adequate to evaluate the impact of the use of a given set of prediction equations in the clinical setting. The analysis of the standardized prediction deviations agrees with the message given in the Results section, except for predicted FEV_1 by PAOLETTI *et al.* [4] in females, which showed the highest underestimation among the five reference equations.

It must be emphasized that the present study was not undertaken to propose new common standards, but only to examine the mean prediction deviations of the five sets of prediction equations (table 2). The study shows that the use of the European Coal and Steel Community (ECSC) equations [2, 7] in the age interval analysed may provoke significant underestimation of spirometric results and it prompts the need for a re-evaluation of the current European recommendations on lung function reference values [7].

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