Spirometry of healthy adult South African men

Part I. Normative values

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Aim. To determine normative spirometric values for black and white South African men.

Methods. A population of 796 bank personnel were subjected to spirometry and anthropometric measurements. An exhaustive questionnaire and radiographic screening process was used to identify a healthy population. Spirometry was performed using two calibrated instruments, a sleeve sealed piston spirometer (Autolink) and a bellows spirometer (Vitalograph). The methodological guidelines of the American Thoracic Society were observed. In the regression analysis Mallow's CP statistic was used to identify the best prediction models.

Results. Compelling evidence was found in support of incorporating sitting height in prediction equations. For the Autolink studies the prediction equations (based on age, standing height and weight) for forced vital capacity (FVC) (litres) were as follows: blacks: 0.053 height – 0.030 age – 3.54; and whites: 0.056 height – 0.038 age – 3.07; for forced expiratory volume in the 1st second (FEV_1) (litres) blacks: 0.036 height – 0.032 age – 1.18; and whites: 0.042 height – 0.038 age – 1.45. For the Vitalograph the equations were: FVC: blacks 0.048 height – 0.024 age – 3.08 L; whites 0.056 height – 0.031 age – 3.42; FEV_1: blacks 0.029 height – 0.027 age – 0.535; whites 0.042 height – 0.036 age – 1.84.

Conclusion. The Vitalograph yielded significantly lower values than the Autolink for FVC measurements despite absolute consistency in methods. In view of the fact that the present study was conducted on healthy men, free from noxious industrial exposure, using state-of-the-art methods, these prediction equations may be regarded as the definitive norms for adult South African males.

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At present a variety of normative spirometry equations are being used in lung function laboratories in South Africa. Several southern African authors have published results of spirometric surveys during the past 5 years.[1-4] Unfortunately these studies have all been hampered by the same epidemiological flaw: they were not specifically designed to develop normative lung function values. Their prediction equations were therefore derived as by-products of surveillance data on populations of workers in dusty industries. Such population selection bias almost certainly contributed to inaccuracies in developing normative equations.

This paper (Part I) describes a survey conducted with the aim of developing normative lung function values for South African men; Part II describes an investigation into the most important determinants of spirometric function.

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Methods

Study population

After an extensive search throughout South Africa, we identified a population of workers who met the following requirements: the population was to consist of adult males who were *not exposed to dust or noxious inhalants* that might affect lung function; the *training effect* should not apply; the *healthy worker* effect should not apply; and large enough groups of blacks and whites of *similar socio-environmental status* (SES) should be identifiable. The selected study group that met these criteria consisted of a group of employees of the (then) Barclays Bank and Barclaycard Group (now known as the First National Bank and Firstcard Group) in central Johannesburg.

'Race'. Cognisant of the complexities embodied in the concept of 'race', we define 'race' by skin colour, either comprising 'whites' or 'blacks'. In this survey no 'coloureds' were included.

Using the Bank's personnel database, 1 192 men who were eligible to enter the study were identified. For administrative reasons 187 were unable to participate. Eventually 782 men (65.6%) in the Bank population were studied and a further 14 men from SA Breweries were included in order to replace some of the higher SES black men in the Bank group who could not participate because of administrative reasons. Excluding those who were unable to participate for administrative reasons, 496 of 591 black men from the Bank (83.9%) and 286 of 414 white men (69.1%) were surveyed — the selection of the white group was deliberately skewed towards lower SES (by current salary) in the hope of obtaining a population more comparable with the black group.

Comparisons between the participants and the non-participants were made using the Bank's personnel file. The two populations were very similar in respect of age distribution, place of birth (urban or rural) and smoking status.

Spirometric survey

Spirometry was performed using two instruments:

1. Morgan transfer test autolink (Autolink; P. K. Morgan Instruments Inc.), sleeve sealed piston spirometer. This apparatus conforms to the American Thoracic Society (ATS)'s requirements, as shown in Table I.[5,6]

Table I. Comparison of minimum ATS/ITS specifications with survey apparatus

	Accepted standards	Survey equipment	
Spirometry FVC/FEV_1	ATS/ITS	Autolink*	Vitalograph (S model)†
Range/accuracy (BTPS l)	7 l ± 3% or 0.050 l	12 l ± 2% or 0.050 l	7.8 l ± 3% or 0.050 l
Flow range (l/s)	0 - 12	0 - 12	0 - 7.8
Time (s)	30 (FVC) 15 (FEV_1)	30 (FVC) 15 (FEV_1)	NS NS
Resistance and back pressure (cm H_2O l/s) from zero to 12 l/s	< 1.5	< 0.2	< 0.4
Time zero	Back extrapolation	Computational back extrapolation	Back extrapolation (manual)
Calibration	3 l + 2 l (2 + 6 s)	3 l + 2 l (2 + 6 s)	3 l + 2 l (2 + 6 s)
Computational software	24 std waveforms Independent lab.	24 std waveforms	N/A

* Morgan Inc.
† Medical Instrumentation.
ATS = American Thoracic Society;[5,6] ITS = Intermountain Thoracic Society;[7] NS = not stated; N/A = not applicable.

2. Vitalograph (S model) bellows spirometer. This instrument is widely used in industry in South Africa, even though it does not meet all the ATS specifications (see Table I). Most subjects were tested in duplicate, using both instruments. A strictly randomised entry protocol determined the order in which the instruments were used for any given subject.

The same instruments were used throughout the survey. Before its commencement both instruments were certified accurate and in good working order by a senior lung function technologist. At the commencement of the survey 48 hours was allowed for stabilisation of the apparatus. The temperature of the clinic was maintained as constant as possible (by the Bank's central air-conditioning), but nonetheless ranged between 20 and 28°C. Barometric pressure (P_B) was read from a mercury barometer which had been calibrated by a barometer expert; daily comparative readings were obtained from the local weather station. P_B and temperature readings were taken during testing of each individual participant as well as at the beginning and the end of each day when calibration checks were done. These barometric and temperature readings were incorporated in the conversion of spirometry readings to body temperature and pressure saturated (BTPS).

Quality control

Biological calibration checks, using a group of 6 people, were done several times during the survey and no instrument drift was noted. **Mechanical calibration checks** were documented twice daily as well as intermittently throughout the day, especially when the throughput was greater than usual. Instruments were tested by fast and slow injections with 3-litre and 1-litre syringes, and (for the Autolink) the spirometer and data processing units were tested independently.

Spirometric measurements were performed with the active encouragement of a qualified, very experienced pulmonary technologist. A minimum of three acceptable forced expiratory manoeuvres were required for completion. Criteria for acceptable reproducibility were based on current ATS recommendations,[6] i.e. that the forced expiratory volume in the 1st second (FEV_1) and forced vital capacity (FVC) values from three acceptable curves should not vary by more than 5% or 0.1 litre, whichever was greater. Criteria for an acceptable test conformed to the ATS recommendations.[6]

Subjects wore nose clips and were studied in the sitting position.

The maximum values of FEV_1 and FVC were used for analysis.[6] These two values were not necessarily taken from the same curve.[6] Data were excluded from the analysis if acceptable traces could not be obtained after several attempts.

All spirometric volumes were reported in BTPS. In the case of the Vitalograph, manual conversion to BTPS was done, using the factors recommended by the Intermountain Thoracic Society (ITS).[7] The software of the Autolink made BTPS conversions.

Anthropometric data, including standing height, sitting height, chest circumference and body mass, were obtained by a qualified nursing sister. Standing height was measured using a tape-measure (affixed to a wall) and a set square; heels, shoulder blades and occiput were positioned against the wall and subjects were measured barefoot. Sitting height was measured using the same tape-measure and set square with subjects sitting erect on a firm wooden chair, with buttocks, shoulder blades and occiput touching the wall.

Chest radiographs, comprising full-sized postero-anterior and lateral radiographs, were taken. These were read by J.G.G. within 48 hours and by a consultant radiologist at Groote Schuur Hospital (Dr Hillel Goodman), as well as by S.J.L.

Radiographic survey. Seven hundred and seventy-eight radiographs were taken within a week of the lung function survey. An additional 5 radiographs had been taken the previous year, and these were reviewed. Thirteen subjects who refused to have radiographs taken (but participated in the rest of the survey) were included in the analysis.

The **ATS-2 questionnaire,** with additional sections to assess childhood SES and current socio-economic and environmental conditions, was administered — these aspects are described fully in Part II. A series of three pilot studies was done to refine modifications to the questionnaire. Interviews were performed by trained, non-medical research assistants. Training was undertaken by

J.G.G. using the ATS methods. Except for 8 interviews (interviewees refused), all interviews were recorded on audio tapes. The interviewing technique was standardised. Coding was checked by a second interviewer and a nursing sister and again checked by J.G.G.; where appropriate, J.G.G. used the tape recordings to confirm that the interviewing technique was being adhered to and that the data were correctly recorded. A 15% sample of interviews was repeated separately by J.G.G. in order to assess reproduceability of these data; a further sample of 20% of the tape recordings was assessed and comparisons made with the coding of the interviewers. Carboxyhaemoglobin levels were done on a random sample of 65 subjects in order to assess the validity of their smoking history.

Statistical analysis. Spirometric data were entered manually on coding sheets, which were then (like the coded questionnaire data) entered into the computer by professional data punchers. This procedure was checked by means of duplicate entry and computer verification.

Data analysis was performed by a professional statistician (G.J.) at the Institute for Biostatistics of the Medical Research Council. The SAS and BMDP statistical packages were used. Descriptive statistics and frequency tables were generated for all subjects who entered the survey, as well as for a subgroup termed 'normal'. Descriptive statistics were given as means and standard deviations (SDs) where data were normally distributed; other results were expressed as medians.

Comparisons of subgroups with regard to categorical variables were done by the chi-squared or Fisher's exact test. Comparisons of subgroups with respect to continuous variables were done using *t*-tests, or median tests where the data were not normally distributed.

Multiple linear regression equations for FEV, and FVC were obtained using anthropometric data, social class indicators and race as independent variables. The goal of the regression analyses was to determine the best prediction equations. (The results of these analyses are presented in Part II.) The criterion used for the selection of regression equations was based on minimising Mallow's CP statistic, which estimates the mean square error of prediction of a given model.[8] Although the R^2 statistic did not play a role in the selection of the best equation, R^2 values are provided in the 'Results' section to allow comparison with other published work. Observations were investigated in terms of standardised residual and Cook's distance to determine whether there were any influential points or outliers which had to be excluded from the analysis. No such points were found.

Ethical permission was obtained from the Medical Faculty Ethics and Research Committee, University of Cape Town. All subjects in this study gave their written consent to participate, on the clear understanding that they could refuse without prejudice in any form.

Results

Descriptive statistics of the total sample

Participants in spirometric tests

In all, 796 men were studied. Because of time constraints, only 702 subjects (88.2%) attempted both the Autolink and the Vitalograph spirometers; 767 (96.4%) attempted the Autolink and 729 (91.6%) the Vitalograph tests. Of these 722 (90.7%) in the Autolink group (flow volume loops) and 693 (87.1%) in the Vitalograph (volume - time curves) met the ATS and ITS standards for acceptability and reproducibility;[6,7] 646 (81.2%) who were tested on both instruments satisfied these standards.

The rejection rate for flow volume loops was slightly greater for blacks (7%) than for whites (3.8%) (χ^2; $P = 0.074$). However, for the volume - time graphs, the rejection rate for blacks (7%) was significantly greater than for whites (1.2%) (χ^2; $P = 0.0001$).

Anthropometric population data

The **age distribution** is shown in Table II. Twenty-three individuals (21 black and 2 white) lacked 'accurate age data' (defined as a discrepancy of > 5 years between the ages stated during the survey, calculated from the stated date of birth or registered in the Bank's personnel records) and were not included in the analyses of age and lung function. The table reflects a strong representation of subjects in the 25 - 54-year age group.

Table II. Age distribution by race categories — frequency and percentage

	Black ($N = 489$)		White ($N = 284$)	
Age group (yrs)	No.	%	No.	%
< 25	15	3.1	24	8.5
25 - 34	138	28.2	75	26.4
35 - 44	191	39.1	87	30.6
45 - 54	107	21.9	55	19.4
55 - 64	36	7.4	28	9.4
⩾ 65	2	0.4	15	5.3

Anthropometric data and age are summarised in Table III. Here it is seen that the mean ages of the white and black groups were similar. Mean sitting height for the white group was significantly higher than for the black group (*t*-test; $P = 0.001$); the same applied to standing height. However, the mean sitting height/standing height ratio of the two groups was identical, namely 0.51.

Questionnaire survey

Smoking history. Smoking histories were obtained from 793 (99.6%) subjects. Lifelong never-smokers formed 39.7% of the study population, similarly distributed among blacks and whites. Previous smokers constituted 17.8% of the study population. The white group tended to have a heavier smoking history (> 10 cigarettes per day in 28.7% compared with 20.5% in blacks). Carboxyhaemoglobin measurements on 65 randomly selected men showed that all but 2 individuals had CoHb levels within 1 SD of the mean 'normal' value for city dwellers. All but 1 of the previous smokers had levels within 1 SD of the mean.

Respiratory health history. The prevalence of 'frequent cough with sputum production' was significantly lower ($P = 0.04$) among the blacks than among the whites. None of the other symptoms was significantly different in the two race groups. Within the black population phlegm production (5.1 v. 10.3%) and wheeze (1.4 v. 5.8%) were less frequently declared in rural-born blacks than in urban blacks,

Table III. Anthropometric results — whole study group v. 'healthy group'

Measurement	Total study group			Healthy group		
		Race			Race	
	All (*N* = 796)	Black (*N* = 510)	White (*N* = 286)	All (*N* = 208)	Black (*N* = 128)	White (*N* = 80)
Age (yrs)						
Mean	40.1	39.8	40.6	39.6	41.1	37.3
SD	10.6	9.4	12.4	10.8	10.2	11.3
Range	20 - 72	20 - 70	21 - 72	20 - 70	20 - 70	22 - 68
No.	773	489	284	203	123	80
Sit. ht (cm)						
Mean	88.2	86.2	91.7	88.4	86.1	91.6
SD	4.3	3.3	3.6	4.3	3.1	3.6
Range	78 - 102	78 - 97	81 - 102	79 - 100	79 - 93	85 - 100
No.	791	507	284	206	127	79
Stand. ht (cm)						
Mean	173.2	170.1	178.8	173.2	169.7	178.8
SD	7.8	6.5	6.8	7.7	6.0	6.8
Range	151 - 195	151 - 195	158 - 206	155 - 206	155 - 191	163 - 206
No.	796	510	286	208	128	80
Weight (kg)						
Mean	75.5	77.4	80.9	76.4	73.7	80.2
SD	13.2	12.5	12.5	12.0	12.2	13.2
Range	45 - 123	45 - 123	48 - 132	45 - 126	45 - 107	53 - 126
No.	796	510	286	208	128	80
Ht ratio						
Mean	0.51	0.51	0.51	0.51	0.50	0.51
SD	0.01	0.01	0.01	0.01	0.01	0.01
Range	0.46 - 0.55	0.46 - 0.55	0.47 - 0.55	0.46 - 0.54	0.46 - 0.54	0.48 - 0.54
No.	791	507	284	206	127	79

Sit. ht = sitting height; Stand ht = standing height; Ht ratio = sitting/standing height ratio.

respectively ($P = 0.01$ in each case). Previous pulmonary tuberculosis was reported by 19 blacks (3.8%) but by none of the whites ($P = 0.001$). Previous exposure to dusty occupations was similar in the two race groups: asbestos 1.6% and 1.1% for blacks and whites, respectively; mining 1.6% and 3.5%; foundries 1.0% and 2.1%; quarries 0.8% and 1.4%; grain 3.3% and 1.5%; other dusty jobs 4.5% and 3.2%.

Quality of the information. In the 66 repeat interviews, minor discrepancies were noted: most of these could be attributed to memory lapses. However, in 2 cases (3%) a history of smoking emerged which had previously been denied. In 11 of the 67 tape-recorded interviews (16.4%) the interviewer coded the absence of previous dusty workplaces, whereas a history of such exposure had actually been given.

Description of healthy group

Definition of healthy individuals

The 'healthy' individuals were defined by the following criteria: (*i*) a normal radiograph; and (*ii*) absence of (*a*) frequent cough, sputum production or a history of chronic bronchitis; (*b*) wheezing that induced shortness of breath, or a diagnosis of asthma; (*c*) any previous severe chest infection with cough productive of sputum requiring bed rest for 3 weeks or more, or previously diagnosed pneumonia; (*d*) a diagnosed history of chronic bronchitis, emphysema, bronchiectasis or cardiac failure; (*e*) a previous history of pulmonary tuberculosis; (*f*) an acute respiratory infection on the day of the survey; (*g*) a history of occupational exposure in a mine, quarry, foundry, grain mill or other environment with chemical fumes, gas or dust; (*h*) a positive smoking history (certain analyses were, however, performed on smokers who were otherwise 'healthy' — these will be indicated; and (*i*) a history of previous chest injury or chest surgery.

Two hundred and eight 'healthy' men were thus identified, of whom 128 were black and 80 white (Table III). One hundred and ninety-five blacks (38.2%) and 94 whites (32.9%) were excluded on the basis of their smoking histories alone. The radiographic survey resulted in the exclusion of 9 blacks (1.8%) and 7 whites (2.4%).

In Table III the age and anthropometric data for the total study population and the 'healthy' group with its 'racial' subdivisions are shown. No significant differences between the total group and the healthy group are apparent.

Analysis of spirometric results

Fig. 1 shows the box plots for FVC measured on the Autolink apparatus in the whole population and 'healthy' populations. The mean FVC was found to be significantly higher in white men than in black men. Similar differences were observed for FEV_1.

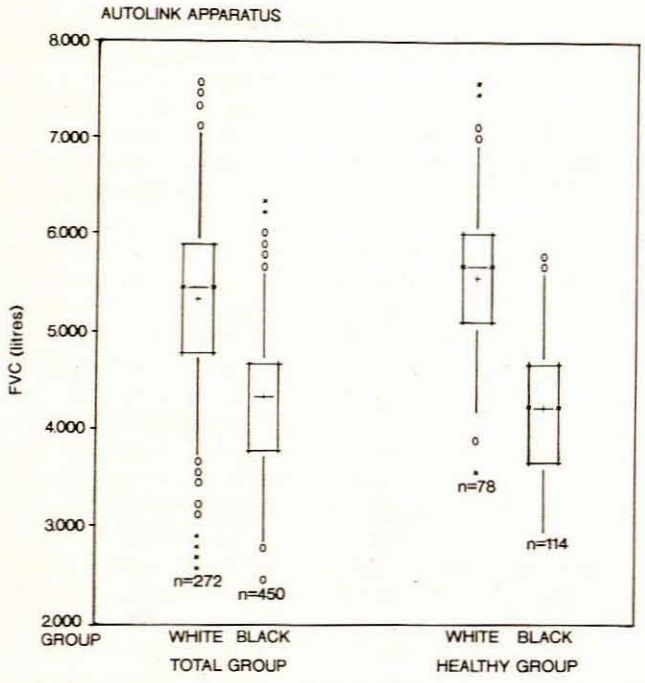

Fig. 1. Box-plots of FVC (Autolink apparatus).

Table IV shows the mean FVC and FEV_1 for the 'healthy' sub-population.

Table IV. Mean (±SD) FVC and FEV_1 in the 'healthy' group

	Vitalograph		Autolink	
	Black (N = 106)	White (N = 73)	Black (N = 114)	White (N = 78)
FVC (l)	4.26 ± 0.6	5.41 ± 0.7	4.26 ± 0.7	5.57 ± 0.8
FEV_1 (l)	3.41 ± 0.5	4.42 ± 0.7	3.57 ± 0.6	4.41 ± 0.7

The predictive equations using standing height, age and 'race' for FVC and FEV_1 are shown in Tables V and VI, respectively.

Table V. FVC prediction equations derived from the 'healthy' group — standing height

	Height	Age	Intercept	R^2
Vitalograph study				
FVC, blacks	0.048	−0.024	−3.08	0.33
FVC, whites	0.056	−0.031	−3.42	0.55
Autolink study				
FVC, blacks	0.053	−0.030	−3.54	0.38
FVC, whites	0.056	−0.038	−3.07	0.57

Table VI. FEV_1 prediction equations derived from the 'healthy' group — standing height

	Height	Age	Intercept	R^2
Vitalograph study				
FEV_1, blacks	0.029	−0.027	−0.535	0.35
FEV_1, whites	0.042	−0.036	−1.84	0.25
Autolink study				
FEV_1, blacks	0.036	−0.032	−1.18	0.33
FEV_1, whites	0.042	−0.038	−1.45	0.27

In the exploratory analyses, using multiple linear regression, a total of 10 different variables as predictors of FVC were examined. These included anthropometric measurements (standing height, sitting height, sitting/standing height ratio, age) as well as 'race' and a variety of other indicators of SES (discussed in Part II). This analysis showed compelling evidence that sitting height and sitting/standing height ratio were superior as predictors of FVC (Table VII) when compared with standing height (Table V), as judged by Mallow's CP values; the R^2 values showed similar trends.

Discussion

The idea for the present investigation had its origin in an article published by Myers,[5] who suggested that elements of SES (nutritional status, respiratory morbidity and

Table VII. Prediction equations for FVC and FEV_1 using age, sitting height and standing/sitting height ratio ('healthy' group)

	Independent variables						
	Sit.ht	Age	Ht ratio	Intercept	R^2	CP	SEE
Vitalograph study							
FVC, blacks (N = 101)	0.112	−0.024	−10.066	0.56	0.36	3.36	0.52
FEV_1, blacks (N = 101)	0.071	−0.027	−5.785	1.36	0.38	2.03	0.45
FVC, whites (N = 72)	0.123	−0.031	15.6	3.28	0.61	3.68	0.48
FEV_1, whites (N = 72)	0.110	−0.034	−12.494	2.61	0.60	3.0	0.51
Autolink study							
FVC, blacks (N = 112)	0.119	−0.029	−11.36	0.965	0.42	3.23	0.52
FEV_1, blacks (N = 112)	0.080	−0.032	−7.57	1.80	0.42	2.34	0.455
FVC, whites (N = 77)	0.123	−0.038	−16.08	3.91	0.62	3.23	0.51
FEV_1, whites (N = 77)	0.093	−0.038	−10.57	2.93	0.59	3.19	0.50

Sit. ht = sitting height; Ht ratio = sitting height /standing height ratio; CP = Mallow's CP value; SEE = standard error of estimate.

occupational exposures) had confounded all previous studies that concluded that there were significant inter-racial differences in spirometric lung functions. Owing to the absence of adequately comparable (in terms of SES) community dwelling groups in South Africa at the time, we were unable to design a community-based study which would have been the most appropriate format for testing Myer's hypothesis. We therefore carried out a workplace-based study, specifically designed to develop normative spirometric values in adult men, with the secondary objective of examining the effects of SES influences. In this respect the bank population provided us with a large healthy population without the biasing influences often found in other industries: no healthy worker effect, occupational training effects or occupational noxious effects were associated with working in the bank. Our study population can therefore be regarded as an adequate approximation of healthy people in the general population, and we believe that our findings may justifiably be extended to the general population. It should be noted, however, that the black group in the present study probably represented a bias towards the higher SES for that 'race' group in South Africa.

We believe that our study comprises the 'state of the art' application of the most rigorous methodological requirements of spirometric surveys — we adhered to the ATS criteria of 1978 and in all respects accurately anticipated the subsequent 'update' criteria which were published in 1987.[5,6] Despite complete uniformity in the methods, significant differences were noted between the Autolink- and Vitalograph-generated vital capacity values. Perhaps this should not be surprising, since the latter apparatus does not fully satisfy the ATS criteria, particularly with regard to the volume of the bellows; subjects with very high lung volumes might have encountered circuit resistance, resulting in an underestimation of lung volume.

Consistent with previous publications, the present study showed blacks to have smaller lungs than whites of similar age and height; our investigations regarding confounding variables (including SES) are described in Part II.

In the context of South African research, it is noteworthy that our prediction equations yield results that are very similar to those of Coetzee and Becker,[3] who studied 518 asbestos cement workers (155 non-smokers) aged 26 - 60 years. They developed an equation yielding a predicted FVC of 4.21 litres (40-year-old black man, 170 cm tall). For the same anthropometric values our predicted FVCs are as follows: Autolink — 4.25 for blacks, 5.08 for whites; Vitalograph — 4.13 for blacks, 4.83 for whites. The close similarity of these prediction equations would suggest that the emphasis on strict methodology in the present study might not be wholly justified; a large field study using less sophisticated, acceptable equipment provides satisfactory approximations of the normative lung function values for adult men. The implication is that future studies to determine normative values for the rest of the population (children, women, the elderly) may provide adequate data without going to the lengths we did in this study.

The present study met the strictest possible criteria with regard to selecting a healthy study group, specifications for apparatus and methods. We contend that it is no longer justifiable for laboratories in this country to use prediction equations that were developed in other countries, and that the equations in this project should be adopted in respect of South African men. Where normative values are adjusted for 'race', it is important to recognise the confounding influences of socio-economic status, as described in Part II.

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