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Spirometric Reference Equations for Semi-Urban and Urban Bantu Cameroonians

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ABSTRACT

Background: Spirometric reference values vary substantially across ethnic groups, and remain largely poorly characterized among Africans. We derived spirometric reference equations for adult Cameroonians and compared their performance with those derived from other ethnic groups. **Methods:** Spirometric variables according to the American Thoracic Society/European Respiratory Society 2005 guidelines were acquired in voluntary healthy non-smoker subjects in Yaounde (Capital City) and Foumbot (semi-urban area in West Region), in Cameroon during November 2011 to January 2012 (Yaounde) and August 2012 (Foumbot). Reference equations were derived separately for men and women from multiple linear regressions. **Results:** A total of 411 subjects (206 men) met the inclusion criteria. The mean age was 39.5 ± 16.1 years (min - max: 18 - 85 years) for men and 39.2 ± 14.1 years (18 - 90 years) for women. Age and height were the only variables significantly associated with spirometric values in the final linear regression models. Derived reference values were lower than those derived from Global Lung Initiative 2012 equations for different ethnic groups, except for the forced expiratory volume in 1 second/forced vital capacity ratio (FEV_1/FVC ratio). The mean FEV_1/FVC ratio was 0.88 ± 0.07 for Cameroonian men and 0.89 ± 0.07 for Cameroonian women. Variations in the performance of derived models in bootstrap internal validation were marginal. **Conclusion:** This study highlights the importance of deriving specific predictive equations for each ethnic group. The use of adjustment factors applied to Caucasian equations when compared with the values derived in our study leads to an overestimation of the values for FEV_1 and FVC.

Keywords: Spirometry; Reference Values; Lung Function; Cameroon; Bantu

1. Introduction

Spirometry is an important tool in the diagnosis and evaluation of the severity of lungs' functional impairment in many respiratory diseases [1,2]. Results obtained from pulmonary function tests are supposed to be interpreted with respect to predicted or theoretical values derived from a given population [1,3]. This is because reference values vary greatly by ethnicity and the absence of spirometric reference values in a given population is a source of erroneous interpretation of spirometric results [1,4].

Race has been consistently shown to be a determinant of pulmonary functions. Caucasians of European descent usually have larger static and dynamic lung volumes and forced expiratory flow rates than their counterparts from most other ethnic groups [1,5-8]. This variability in lung volumes can be partially explained by the length of the chest-to-height ratio, which partially accounts for the low forced expiratory volume in the first second (FEV_1) and forced vital capacity (FVC) in Blacks and other races compared with Caucasians [3].

Reference values and predictive equations for different spirometric variables are well characterized in most races/ethnic groups [4,9]. To our knowledge, however,

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only few studies on spirometric reference values have been conducted in Black Africans [10-13]. Most of the available studies were conducted more than 20 years ago, with the exception of studies by Hnizdo *et al.* in South Africa [14] and Knudsen *et al.* [15] in Tanzania. Furthermore, Hnizdo's study [14] focused on healthy miners workers, and Knudsen's study [15] included only 52 men and 98 women. The recently published multiracial references equations of the Global Lung Initiative (GLI) among the age group 3 - 95 years [9], did not account for Black Africans, in the absence of specific data for this population.

In Cameroon, to the best of our knowledge, no study on predictive values for spirometric variables among healthy individuals has been published. Given the importance of those values in routine clinical setting and the need for guiding decision making with accurate estimates, it has been internationally recommended that reference values for pulmonary function tests used in a given population be those derived from the same population, and not extrapolations from reference values from another population [1,3]. The aim of this study was to derive and validate spirometric reference equations for Bantu native adult Cameroonians.

2. Materials and Methods

2.1. Study Setting and Participants

This cross-sectional study was conducted in Yaounde (Capital city) and Foumbot (semi-urban area in West Region), in Cameroon during November 2011 to January 2012 (Yaounde) and August 2012 (Foumbot). Ethnic homogeneity was achieved by including only Bantu Cameroonians. The recruitment of voluntary subjects in Yaounde was done at the Yaounde Jamot Hospital (YJH) and community setting where subjects could easily be recruited, including worship and quarter gathering places. In Foumbot, subjects were recruited from four health care centers during a health campaign which attracted about 850 people from the community. All Bantu Cameroonian subjects living in Yaounde and Foumbot aged 18 years and above found at the different recruitment sites during the visit of the research team, were invited to take part in the study. "Healthy" subjects were selected with the help of a questionnaire inspired from the respiratory American Thoracic Society (ATS) and the National Heart and Lung Institute (NHLI) Division of Lung Diseases (DLD) questionnaire (ATS/DLD-78 A questionnaire) [16]. The study was approved by the Cameroon National Ethics Committee (authorization N˚276/CNE/SE/2011).

2.2. Assessment of the Predictors

Consenting participants answered a questionnaire and received a physical examination to confirm their eligibility. Height (m) was measured in standing position against a vertical wall, with the subject's head erect in the Frankfort horizontal plane using stadiometer. Weight (kg) was measured using a Soehnle scale (Soehnle-Waagen GmbH & Co. KG, Wilhelm-Soehnle-Straße 2, D-71540 Murrhardt/Germany). The body mass index (BMI, in kg/m^2) was calculated as weight (kg)/height*height (m^2). Subject's dry weight and body surface area (BSA, measured in m^2) were estimated respectively using the James formula and the Boyd formula [17]. Blood pressure (mmHg) was recorded at rest (>15 minutes), on the right arm with an OMRON M6 (Omron Santé France, Rosny sous-bois, France) automated device and appropriate cuff size.

Subjects were excluded if they presented one of the following characteristics: current respiratory symptoms; past history of diseases which could interfere with lung functions such as asthma, chronic bronchitis, chronic obstructive pulmonary disease (COPD), tuberculosis, cardiac failure, angina, myocardial infarction, uncontrolled high blood pressure, diabetes mellitus and stroke; current and ex-smokers totalizing more than 5 pack-years of tobacco use; ongoing treatment with β-blockers or bronchodilators; obesity; BMI < 18.5 kg/m^2; pregnancy; deformed vertebral column; poor performance on spirometry tests.

2.3. Measurements of Spirometric Variables

Spirometric variables were measured with the use of a digital Fleisch type pneumotachograph (spirolyser SPL-10 USB, FIM-Medical, Lyon-France) in Yaounde or a digital turbine spirometers (spiroUSB, Care fusion, Yorba Linda-USA) in Foumbot. The two machines followed the ATS 1994 standards [18]. All the pulmonary volumes and flow rates were automatically corrected for body temperature and pressure saturated, and the pneumotachograph was calibrated every morning using a 3 L calibration syringe. The measurements were done from 9 am to 6 pm (GMT + 1) by the same experienced technician. Variations in climatic conditions were taken into consideration during the course of the measurements and the device was reconfigured accordingly. Variations in atmospheric pressure were recorded three times per day, while temperature and hygrometry were recorded every hour. All measurements were done under the direct supervision of an experienced pneumologist (EWPY).

The different spirometric variables measured were: the forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF), forced expiratory flow 25% - 75% ($FEF_{25\%-75\%}$), and the FEV_1/FVC ratio. The acceptability and reproducibility criteria recommended by the ATS and European Respiratory

Society (ERS) guidelines (ATS/ERS guidelines) were respected [1]. At least three maneuvers up to a maximum of eight were performed as required to obtain the flow rate curve (FVC curve). A one minute resting period was observed between consecutive maneuvers. Satisfactory exhalation was considered in the presence of any of the following: 1) no change in exhaled volume (plateau on the volume-time curve) for 1 second after an exhalation time of at least 6 seconds; 2) the presence of a reasonable duration or plateau in the volume-time curve; 3) inability of the subject to continue to exhale [1,18].

The largest values for FEV_1 and FVC from three acceptable maneuvers were retained. The authorized difference between the largest values of FVC or FEV_1 of the three acceptable maneuvers was inferior or equal to 0.150 L or 5%. The maneuver with the largest sum of FEV_1 and FVC was used to determine $FEF_{25\%-75\%}$. For the peak flow, the largest value obtained after three acceptable maneuvers was retained and the authorized difference between the two highest values was at maximum 0.65 L/s [1].

2.4. Statistical Analysis

Statistical analysis was performed using the SPSS for window version 17 (SPSS Inc., Chicago, IL) and SAS/STAT® v 9.1 for windows (SAS Institute Inc., Cary, NC, USA). Results are expressed as mean ± standard deviation, median and 25^{th} - 75^{th} percentiles, and count and percentages.

2.4.1. Prediction Models Development

Multiple linear regression models were used to relate each of the five targeted spirometric variables with potential predictors, separately in men and women. Candidate predictors included age, weight, height, BMI and BSA, which are all known to be related with the spirometric indices. Bivariate Pearson's correlation tests and matrix graph were used to investigate the shape and significance of the associations of candidate predictors with each of the spirometric indices. Significant predictors in bivariate association (p-value < 0.10 for the correlation test) were then entered all together in the same multivariable models and backward elimination procedures used to retain the most significant predictors in the final model (based on a p-value < 0.05). For competing final regression models, the one with the highest coefficient of determination (R^2) and lowest standard error of the estimate (SEE) was retained. Appropriate procedures were used to check the adequacy of the final models.

2.4.2. Prediction Models Validation and Comparison

Internal validation of the derived models used the bootstrap resampling procedures, which were based on 1000 replications [19]. In brief, the population used to derive models was resampled with replacement 1000 times, each sample being of the same size and sex composition as the original population. From each bootstrap sample, new sex-specific models were developed using predictors in the final model. The regression coefficients from each bootstrap sample were then applied both to the relevant bootstrap sample and the original population to predict the spirometric indices of interest. The difference in the performance measures of the model on the bootstrap sample and the original population was then recorded and averaged across the 1000 replicates to characterize the *optimism.* A prediction model would always tend to perform better when it is tested on the same sample used to develop the model (self-fulfilling prophecy), as opposed to when the same model is tested on a new sample. Optimism reflects the drop in the observed models' performance on the derivation sample that should be expected when the model is tested on a new sample.

The values of the spirometric variables derived from the new reference equations were compared with directly measured values and values from Caucasians, Asian, Africans and African-Americans. Differences in mean values across the different race/ethnic group were graphically illustrated using the age of all the participants with a height of 1.70 m for men and 1.60 m for women.

The upper and lower limits of each spirometric variable were determined by a 90% confidence interval (CI). The confidence interval was calculated using the residual standard deviation (RSD) according to the formula: 90% CI = predicted or reference value ± 1.645RSD. Primary analyses were based on the natural form of each of the candidate predictor, and plots of residuals against the predicted values used to check the adequacy of models. However, in a sensitivity analysis, we also tested the effect of different coding of variables in the final models (SAS *transreg* procedures) and tested the effect of using robust regression procedures (SAS *robustreg* procedures). We investigated the effects of recruitment city (Yaounde vs. Foumbot) on parameter estimates in final model through interactions tests. Finally, the age distribution of our population was skewed in a favor of younger people, likely reflection the age structure of the background population. To test the likely effect of this age structure on the performance of derived model, the upper quarter of our sample was artificially inflated (to 3 times their original number) by sampling at random with replacement participants within this age bracket, up to a sex-specific sub-sample of twice their number in the original sample (using the SAS *survey select* procedures), which was then added to the original sample. The performance of linear regression models from this inflated sample was then assessed.

3. Results

3.1. Study Population

During the recruitment phase, we questioned and examined 832 participants, among whom 136 subjects did not meet the inclusion criteria and were excluded from the study. Of the 696 remaining participants, 285 subjects were further excluded for poor spirometric maneuvers, **Table S1**. Therefore, 411 subjects (206 [50.1%] being men) were included in the final analytic sample (**Figure S1**). Their mean age (standard deviation) was 39.5 (16.1) years for men (minimum - maximum 18 - 85 years) and 39.2 (14.1) years for women (18 - 90 years). The standing height ranged from 1.55 m to 1.97 m for men, and from 1.44 m to 1.85 m for women (**Table 1**).

Table 1. Range, mean and median values of anthropometric variables by sex.

Parameters	Men (n = 206)	Women (n = 205)
Age, years		
Minimum - maximum	18 - 85	18 - 90
Mean (SD)	39.5 (16.1)	39.2 (14.1)
Median (1^{st} - 3^{rd} quartiles)	35.5 (26 - 50.3)	38 (27.5 - 49.5)
Standing height, m		
Minimum - maximum	1.55 - 1.97	1.44 - 1.85
Mean (SD)	1.72 (0.07)	1.63 (0.07)
Median (1^{st} - 3^{rd} quartiles)	1.72 (1.67 - 1.80)	1.63 (1.58 - 1.67)
Weight, Kg		
Range	54 - 110	49 - 94
Mean (SD)	72.3 (8.9)	66.4 (9.1)
Median (1^{st} - 3^{rd})	71 (66 - 77)	66 (59.5 - 72.5)
Body mass index, Kg/m^2		
Minimum - maximum	18.7 - 29.7	18.6 - 29.9
Mean (SD)	24.4 (2.5)	25.1 (3.0)
Median (1^{st} - 3^{rd} quartiles)	24.1 (22.5 - 26.2)	25.4 (23 - 27.4)
Lean weight, Kg		
Minimum - maximum	44.5 - 81.1	36.4 - 60.7
Mean (SD)	56.7 (5.4)	46.0 (4.4)
Median (1^{st} - 3^{rd} quartiles)	56.3 (53.1 - 59.5)	45.9 (42.9 - 49.0)
Body surface area, m^2		
Minimum - maximum	1.54 - 2.45	1.43 - 2.17
Mean (SD)	1.86 (0.14)	1.73 (0.14)
Median (1^{st} - 3^{rd} quartiles)	1.85 (1.76 - 1.93)	1.72 (1.62 - 1.83)

3.2. Correlation between Spirometric Variables and Candidate Predictors

Sex-specific Pearson's correlation coefficients and p-value for the relationships of spirometric indices with candidate predictors are shown in the **Table S2**. Age and height were the variables consistently and significantly associated with spirometric indices.

3.3. Spirometric Reference Equations

Age and height were the two variables which were found to be consistently and significantly associated to spirometric indices in multivariable analyses. Adding of other candidate predictors (lean weight, BSA, BMI), the squared term of age, or switching to robust regression procedure did not improve the fit of models. All age*city and height*city interactions tested were non significant (**Table 2**). Therefore the final reference spirometric equation for each of the spirometric indices is given by the formula: *Spirometric index = intercept +* $\beta 1 x Age$ *+* $\beta 2 x Height$ (**Table 3**).

The performances of models based on various coding of predictors are shown in **Table S3**. Substantial improvement in the R^2 was observed for models based on the following transformations of predictors: Monotonic transformation, iterative smoothing splines transformation, or when the number participants in the upper quarter of the age distribution was inflated (**Table S4**). In spite of these improvements, the small number of participants precluded any reliable derivation of final models based on those transformations, to reduce the risk of over-fitting, although the application of any such model in routine practice can be quite challenging.

3.4. Internal Validation of Prediction Models

The summary statistics for internal validation of models using bootstrap procedure are provided in **Table S5**. For each of the spirometric index considered, the average of the regression coefficients across bootstrap samples was not appreciably different from those obtained on the original population, indicating that any gain from shrinking those coefficients would be marginal. As expected, the performance of bootstrap derived model based on the R^2 and adjusted R^2 was always better on the bootstrap sample than on the original sample, reflecting the well-known "*self-fulfilling prophecy*", which indicate the fact that a model will always tend to perform well when it is tested on the same population that was used to develop the model. However, differences in performance measures (*optimism*) were mostly marginal. In both the bootstrap samples and the original population, the slope of the relationship predicted vs. observed spirometric index was always closed to unity, indicating near prefect agreement between observed and predicted spirometric indices

Table 2. Spirometric reference equations for Cameroonian adult subjects aged 18 - 90 years old.

Parameters	Intercept	β_1 age	β_2 height	R^2	Adjusted R^2	RSD	p-values interaction	
							Age*city	Height*city
Men (n = 206)								
FEV_1, L	−1.933	−0.027	3.609	0.485	0.480	0.56361	0.846	0.540
FVC, L	−2.549	−0.029	4.266	0.477	0.471	0.63537	0.230	0.783
PEF, L/s	−0.814	−0.038	5.429	0.132	0.124	2.00442	0.053	0.715
$FEF_{25\%-75\%}$, L/s	1.321	−0.035	2.301	0.233	0.225	1.12148	0.974	0.830
FEV_1/FVC	0.959	−0.00043	−0.034	0.009	0.0005	0.07118	0.049	0.675
Women (n = 205)								
FEV_1, L	−1.398	−0.023	2.848	0.397	0.391	0.46454	0.461	0.496
FVC, L	−1.791	−0.024	3.276	0.390	0.383	0.51956	0.200	0.427
PEF, L/s	−4.453	−0.038	6.695	0.229	0.221	1.30100	0.690	0.423
$FEF_{25\%-75\%}$, L/s	−1.221	−0.025	3.271	0.175	0.167	0.92353	0.153	0.279
FEV_1/FVC	0.993	−0.00022	−0.045	0.006	0.004	0.05564	0.011	0.733

$FEF_{25\%-75\%}$, forced expiratory flow 25% - 75%; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF, peak expiratory flow; RSD, residual standard deviation; R^2, determination coefficient; Liter; L/s, liter per second.

Table 3. Comparison of mean values of spirometric variables and percentage difference in mean pulmonary function from prediction equations of current study and other race/ethnic groups.

Reference equations	Men						Women					
	FEV_1, L		FVC, L		FEV_1/FVC		FEV_1, L		FVC, L		FEV_1/FVC	
	Mean	% difference	Mean	% difference	Mean	% difference	Mean	% difference	Mean	% difference	Mean	% difference
Current study	3.21	/	3.65	/	0.88	/	2.33	/	2.60	/	0.89	/
Caucasian GLI 2012 [9]	3.91	+21.8%	4.80	+31.5%	0.82	−7.3%	2.97	+27.5%	3.58	+37.7%	0.83	−6.7%
Black American GLI 2012 [9]	3.32	+3.4%	4.06	+11.2%	0.82	−7.3%	2.58	+10.7%	3.10	+19.2%	0.84	−5.6%
North East Asian GLI 2012 [9]	3.78	+17.8%	4.60	+26%	0.83	−5.7%	2.95	+26.6%	3.51	+35%	0.85	−4.5%
South East Asian GLI 2012 [9]	3.58	+11.5%	4.26	+16.7%	0.84	−4.5%	2.66	+14.2%	3.10	+19.2%	0.86	−3.4%
Other/mixed GLI 2012 [9]	3.65	+13.7%	4.42	+21.1%	0.83	−5.7%	2.79	+19.7%	3.31	+27.3%	0.86	−3.4%
Tanzanian 2012 [15]	3.13	−2.5%	/	/	/		2.23	−4.3%	/	/	/	/

FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; GLI, Global Lung Initiative.

(**Table S5**). Again, the *optimisms* for the estimates were mostly marginal.

3.5. Model Comparisons

Mean values of the main spirometric indices obtained from prediction equations derived in current study, together with values obtained by applying reference equations from other race/ethnic group to our study population are depicted in **Table 3**, complemented by the illustration in **Figure 1**. The mean value for FEV_1 derived from our study was 3.21 L for men and 2.33 L for women. Equivalent figures were of 3.91 L (% variation: +21.8%) and 3.32 L (+27.5%) using the Global Lung Initiative equations 2012 (GLI 2012) [9] for Caucasians and 3.32 L (+3.4%) and 2.58 L (+10.7%) when applying the GLI 2012 equation for African-Americans. Values from Tanzanians equations [15] were 3.13 L (−2.5%) for men and 2.23 L (−4.3%) for women. Further comparisons for

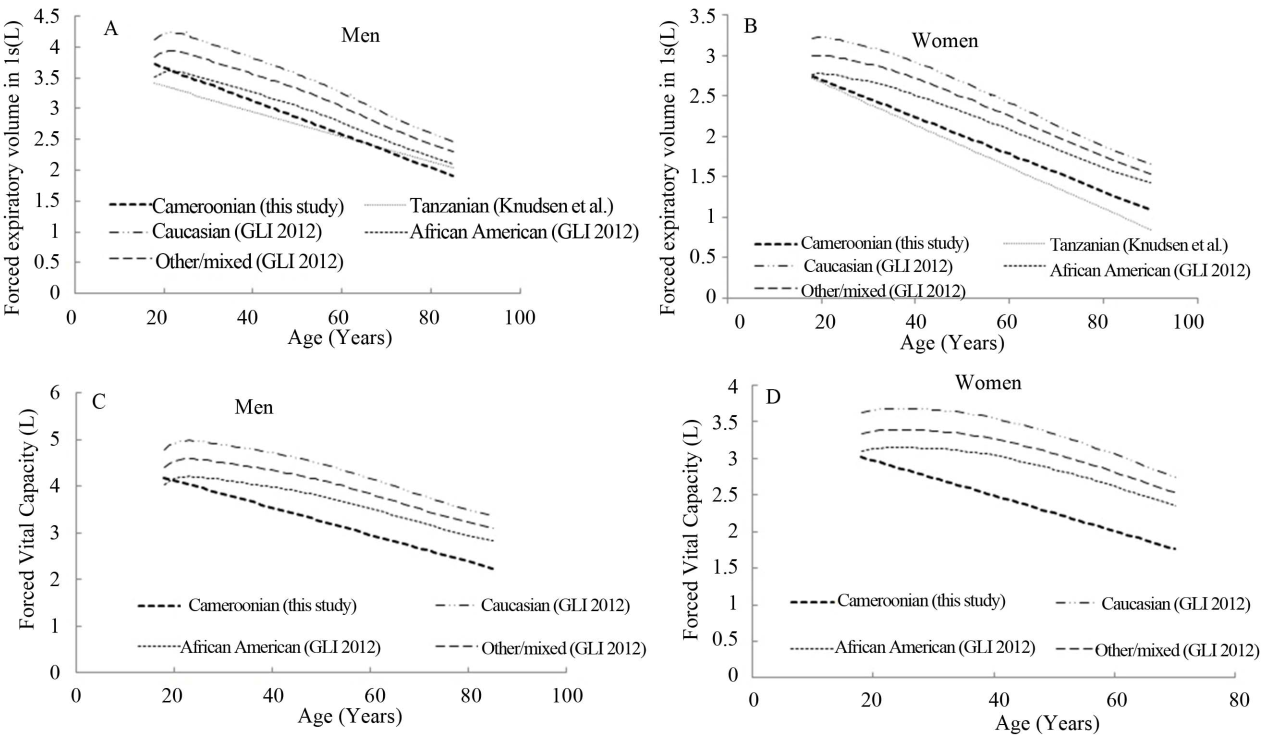

Figure 1. Comparative curved of predicted FEV_1 (forced expiratory volume in one second) and FVC (forced vital capacity) values from various reference equations, ploted against age; for participant with a fixed height on 1.70 m for men (panels (A) and (C)) and 1.60 m for women (panels (B) and (D)). Predicted FEV_1 and FVC values were obtained by applying reference equations of other race/ethnic groups to relevant participants in our sample, GLI, Global Lung Initiave equations.

other indices largely showing similar patterns are summarized in **Table 3**.

4. Discussion

The aim of this study was to derive and validate spirometric reference equations for healthy Bantu urban populations in Cameroon. The main findings of this study are: 1) with the exception of FEV_1/FVC ratio, average spirometric indices in this population are lower than those in populations of other ethnic groups (Caucasians, Asians, African-Americans); 2) as a consequence, spirometric reference values of this population could not be accurately predicted from equations derived in African Americans or by applying an adjustment factor to those derived in Caucasians 3) new equations derived from our sample showed good performance, with only clinically trivial changes in the performance during bootstrap internal validation, and outperformed several equations derived from other ethnic groups.

We included voluntary adults in different sites of the study. This method of sampling "healthy" subjects is acceptable as an alternative to random sampling so far as the selection criteria and the distribution of anthropometric characteristics remain adequate [1]. Also Van Ganser *et al.* [20] found that for lung function measurements, the method of selection, with exception of using hospital patients did not appear to influence either mean values or their ranges. The age of the participants varied from 18 to 90 years and their height was between 1.44 and 1.97 m, which will allow the equations derived to be used on a large proportion of the native Cameroonian population. We believe that the sample size (206 men and 205 women) is satisfactory to establish spirometric reference equations. In fact, international societies recommend a minimum size of 150 men and 150 women for the validation of reference equations [21]. Other major Cameroonian ethnic groups like Peuls, Pygmees and Soudanese were not included. Therefore, caution should be exercised when extrapolating findings from this study to these groups.

Independent variables included in the different equations were those with the highest correlation coefficient. Like in most studies, only the age and the height were definitely included in the prediction equation for FEV_1, FVC, PEF and $FEF_{25\%-75\%}$ and FEV_1/FVC ratio. In this study, we also determined the lower limit of normal of spirometric variables in particular for the FEV_1/FVC ratio. In fact, the overestimation of obstructive respiratory syndromes in old persons and their underestimation in younger persons due to the fix value of 0.70 for FEV_1/FVC ratio led to the use of the lower limit of normal in the diagnosis of airway obstruction [22].

Predicted values for FEV_1 for men and women obtained from the current study were close to values obtained by applying the Tanzanian equations to our population. They were slightly lower than those derived from the African-American equations (maximum of 10% variation) [9]. When compared with GLI 2012 [9] values for Caucasians, North Asians, South Asians and other/mixed ethnic groups, Cameroonian FEV_1 was lower with variation ranging from 11.5% to 27.5%. Application of an adjustment factor of 0.87 to Caucasian equations to derive FEV_1 values for Black Africans led to an unacceptable overestimation. The variability of FEV_1 with respect to the race/ethnic group is well known [1,3] and is partially explained by the ratio between the length of the trunk to the height. But this ratio does not explain all the differences since the utilization of sitting height does not remove all the differences observed across the races [1,12,15].

Values for FVC obtained in the current study were lower compared to values obtained by applying equations to different race/ethnic groups. Applying the suggested adjustment factor for Blacks [3] to the Caucasians equations led to an overestimation of predicted FVC values in our population. These differences have been explained in terms of several factors, most related to characteristics of body size and shape, which might be attributed to a large trunk. Difference in socio-economic standard could also play a role. A significant portion of the reported ethnic differences are determined by socio-economic variables including nutrition which influences the development of muscles [23]. The socio-economic status of the subjects of the current study were not determined and the effects of socio-economic factors could not be investigated.

Our predicted values for the FEV_1/FVC ratio were higher than those from Caucasians and Black Americans equations. The variation of FEV_1 found in our study compared with other ethnic groups is relatively less important when compared with FVC values; this explains a higher FEV_1/FVC ratio value in our study. However, the high FEV_1/FVC ratio found in this study was also found in the Middle East populations [24]. For example, this ratio was 0.86 and 0.87 for Iranian men and women respectively when applying their predictive equations to our population. The ratio FEV_1/FVC from published studies suggested similar relationship between FEV_1 and FVC across different ethnic groups [24]. The relationship found in our study is at variance with findings from other ethnic subgroups, perhaps with the exception of Persians in Iran [9,24]. Indeed, in our study, FEV_1 is closer to FVC than reported in other ethnic groups.

The main limitation of this study is the high rate of excluded participants. The rate of poor quality maneuvers in our study is much higher than what has been reported in the literature. Indeed, 80% of the poor maneuvers originated from our semi-urban site, where a large number of participants are either illiterate or have not gone beyond basic education. These participants would tend to be more conversant with their local dialects, and less able to accurately receive instructions in English or French, regarding spirometry tests. This just reflects the challenge of performing this type of study in the African setting. Although we were dealing only with a Bantou population, the myriad of dialects they used precluded the use of translators.

In conclusion, this study highlights the importance of deriving predictive equations for each ethnic group. The use of adjustment factors applied to Caucasian equations when compared with the values derived in our study led to an overestimation of the values for FEV_1 and FVC. Elsewhere, the FEV_1/FVC ratio and its lower limit in our population appeared to be higher compared with those of Caucasians. This emphasizes on the importance of using appropriate reference values that are specific to the being tested. The reference values derived from this study will contribute to a more accurate interpretation of lung function testing for an early diagnosis and a better classification of respiratory diseases among Bantu populations.

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Supplementary

Table S1. Distribution of factors that led to the exclusion of some subjects.

Criteria	Number of exclusions	Percentage (%)
Obesity	70	16.6
Smoking	16	3.8
History of respiratory diseases	15	3.6
History of cardiovascular diseases	9	2.1
Respiratory symptoms	6	1.4
Refusal	5	1.2
Others	15	3.6
Poor spirometric manoeuvres	285	67.7
Total	**421**	**100**

Table S2. Pearson's correlation coefficient (and p-value) for the relationship between respiratory variables and potential predictors among Bantu men and women.

Parameters	Men (n = 206)						Women (n = 205)					
	Age (years)	Height (m)	Weight (kg)	BMI (kg/m^2)	Body surface area (m^2)	Lean weight (kg)	Age (years)	Height (m)	Weight (kg)	BMI (kg/m^2)	Body surface area (m^2)	Lean weight (kg)
FEV1, L	−0.566 (<0.001)	0.383 (<0.001)	0.115 (0.099)	−0.188 (0.007)	0.213 (0.002)	0.032 (0.645)	−0.512 (<0.001)	0.297 (<0.001)	0.091 (0.197)	−0.103 (0.141)	0.209 (0.003)	0.182 (<0.009)
FVC, L	−0.548 (<0.001)	0.417 (<0.001)	0.143 (0.040)	−0.169 (0.015)	0.245 (<0.001)	0.265 (<0.001)	−0.493 (<0.001)	0.303 (<0.001)	0.086 (0.219)	−0.113 (0.107)	0.213 (0.002)	0.180 (0.010)
PEF, L/s	−0.270 (<0.001)	0.121 (0.083)	0.160 (0.012)	−0.034 (0.628)	0.162 (0.020)	0.171 (0.014)	−0.313 (<0.001)	0.276 (<0.001)	0.137 (0.050)	−0.056 (0.422)	0.193 (0.006)	0.227 (0.001)
$FEF_{25-75\%}$, L/s	−0.420 (<0.001)	0.178 (<0.011)	0.065 (0.356)	−0.104 (0.137)	0.113 (0.106)	0.124 (0.076)	−0.322 (<0.001)	0.253 (<0.001)	0.120 (0.086)	−0.009 (0.895)	0.174 (0.013)	0.175 (0.012)
FEV_1/FVC	−0.100 (0.153)	−0.090 (0.200)	−0.097 (0.167)	−0.060 (0.393)	−0.109 (0.118)	−0.109 (0.119)	−0.198 (0.004)	−0.058 (0.411)	−0.065 (0.356)	−0.031 (0.656)	−0.063 (0.369)	−0.058 (0.405)

FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF, peak expiratory flow; $FEF_{25\%-75\%}$, forced expiratory flow 25% - 75%.

Table S3. R^2 from models with different codings of the predictors.

Predictors	Coding/model	Men (n = 206)					Women (n = 205)				
		FEV_1	FVC	PEF	$FEF_{25\%-75\%}$	FEV_1/FVC	FEV_1	FVC	PEF	$FEF_{25\%-75\%}$	FEV_1/FVC
Age, height	Untransformed	0.485	0.477	0.132	0.233	0.009	0.397	0.390	0.229	0.175	0.006
	Robust regression	0.386	0.367	0.126	0.220	0.027	0.298	0.283	0.188	0.156	0.004
	Log transformation	0.457	0.449	0.113	0.203	0.010	0.362	0.358	0.209	0.154	0.004
	Quadratic response surface transformation	0.495	0.485	0.174	0.263	0.018	0.419	0.405	0.262	0.221	0.029
	Splines transformation	0.495	0.485	0.196	0.268	0.025	0.423	0.411	0.262	0.226	0.063
	Multiple splines transformation	0.494	0.483	0.161	0.260	0.011	0.418	0.405	0.260	0.212	0.014
	Monotonic transformation	0.551	0.541	0.247	0.329	0.054	0.491	0.484	0.316	0.278	0.075
	Piecewise polynomial transformation	0.495	0.485	0.196	0.268	0.025	0.423	0.411	0.262	0.226	0.063
	Iterative smoothing splines transformation	0.663	0.650	0.534	0.557	0.394	0.633	0.651	0.495	0.445	0.380
	Untransformed (upper quarter inflated)	0.558	0.546	0.220	0.319	0.031	0.511	0.502	0.330	0.266	0.012

Table S4. Spirometric reference equations for Cameroonian adult subjects aged 18 - 90 years old based on the sample with the upper age quarter inflated.

Parameters	Intercept	β_1 age	β_2 height	R^2	Adjusted R^2	RSD
Men (*n* = 308)						
FEV_1, L	−1.36486	−0.02812	3.30574	0.558	0.555	0.53789
FVC, L	−2.58951	−0.02965	4.30518	0.546	0.543	0.61360
PEF, L/s	−2.74393	−0.04343	6.70616	0.220	0.215	1.89191
$FEF_{25\%-75\%}$, L/s	2.92739	−0.04000	1.48320	0.319	0.315	1.09798
FEV_1/FVC	1.13605	−0.00059	−0.13348	0.031	0.025	0.07129
Women (*n* = 307)						
FEV_1, L	−1.38976	−0.02566	2.91222	0.511	0.507	0.4577
FVC, L	−1.80463	−0.02763	3.35546	0.502	0.499	0.50921
PEF, L/s	−5.67688	−0.04318	7.60404	0.330	0.326	1.28092
$FEF_{25\%-75\%}$, L/s	−1.40769	−0.03086	3.51974	0.266	0.261	0.93511
FEV_1/FVC	1.00290	−0.00036	−0.04628	0.012	0.006	0.05613

$FEF_{25\%-75\%}$, forced expiratory flow 25% - 75%; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF, peak expiratory flow; RSD, residual standard deviation; R^2, determination coefficient; L, litres; L/s, litres per second.

Table S5. Models validation statistics.

Indices	**Intercept (SD)**	**β_1 age (SD)**	**β_1 height (SD)**	**Boot sample**				**Original population**				**Optimism**			
				R^2 **(SD)**	R^2-adj **(SD)**	b_0 **(SD)**	b_1 **(SD)**	R^2 **(SD)**	R^2-adj **(SD)**	b_0 **(SD)**	b_1 **(SD)**	R^2	R^2-adj	b_0	b_1
Men															
FEV1	−1.904 (0.927)	−0.027 (0.002)	3.590 (0.538)	0.483 (0.070)	0.481 (0.071)	0.007 (0.227)	0.994 (0.171)	0.481 (0.034)	0.478 (0.034)	0.005 (0.249)	0.997 (0.101)	0.003	0.003	0.002	−0.003
FCV	−2.539 (1.069)	−0.029 (0.003)	4.260 (0.611)	0.481 (0.054)	0.478 (0.054)	0.0002 (0.0055)	1.000 (0.004)	0.474 (0.004)	0.472 (0.004)	0.002 (0.238)	0.999 90.068)	0.006	0.006	−0.003	0.0003
PEF	−0.634 (3.152)	−0.038 (0.007)	5.314 (1.597)	0.140 (0.047)	0.135 (0.047)	0.005 (0.115)	1.000 (0.012)	0.131 (0.030)	0.127 (0.030)	−0.053 (1.225)	1.010 (0.175)	0.008	0.008	0.059	−0.009
$FEF_{25\%-75\%}$	1.365 (1.791)	−0.035 (0.004)	2.284 (1.016)	0.236 (0.053)	0.232 (0.053)	−0.014 (0.171)	0.999 (0.017)	0.229 (0.008)	0.225 (0.008)	−0.026 (0.488)	1.003 (0.118)	0.007	0.007	0.012	−0.004
FEV1/ FVC	0.996 (0.203)	−0.001 (0.003)	−0.019 (0.218)	0.007 (0.021)	0.022 (0.021)	0.015 (0.071)	0.993 (0.085)	0.007 (0.008)	0.002 (0.008)	0.375 (0.828)	0.576 (0.939)	0.013	0.013	−0.368	0.417
Women															
FEV1	−1.395 (0.029)	−0.022 (0.895)	2.842 (0.002)	0.396 (0.002)	0.393 (0.002)	−0.0005 (0.0005)	1.002 (0.002)	0.392 (0.023)	0.389 (0.023)	−0.012 (0.221)	1.007 (0.142)	0.003	0.003	0.011	−0.005
FCV	−1.801 (0.994)	−0.024 (0.003)	3.281 (0.615)	0.391 (0.058)	0.388 (0.058)	0.0002 (0.0042)	1.000 (0.003)	0.386 (0.005)	0.383 (0.005)	−0.005 (0.243)	1.002 (0.096)	0.005	0.005	0.005	−0.001
PEF	−4.516 (2.229)	−0.037 (0.007)	6.724 91.370)	0.234 (0.059)	0.230 (0.059)	0.001 (0.029)	1.001 (0.032)	0.226 (0.015)	0.222 (0.015)	−0.020 (0.704)	1.005 (0.146)	0.008	0.008	0.021	−0.004
$FEF_{25\%-75\%}$	−1.220 (1.696)	−0.025 (0.005)	3.274 (1.070)	0.181 (0.056)	0.177 (0.057)	0.0007 (0.046)	0.997 (0.035)	0.171 (0.008)	0.167 (0.008)	−0.038 (0.553)	1.009 (0.180)	0.010	0.010	0.039	−0.012
FEV1/FVC	0.975 (0.302)	−0.0004 (0.002)	−0.020 (0.339)	0.017 (0.021)	0.013 (0.021)	0.007 (0.078)	0.993 (0.086)	0.004 (0.006)	0.001 (0.006)	0.578 (0.979)	0.366 (1.074)	0.016	0.016	0.020	−0.022

$FEF_{25\%-75\%}$, forced expiratory flow 25% - 75%; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF, peak expiratory flow; R^2, coefficient of determination; R^2-adj, adjusted R^2; SD, standard deviation; b_0-b_1, intercept and slope of the linear relationship of the observed versus predicted spirometric indice.

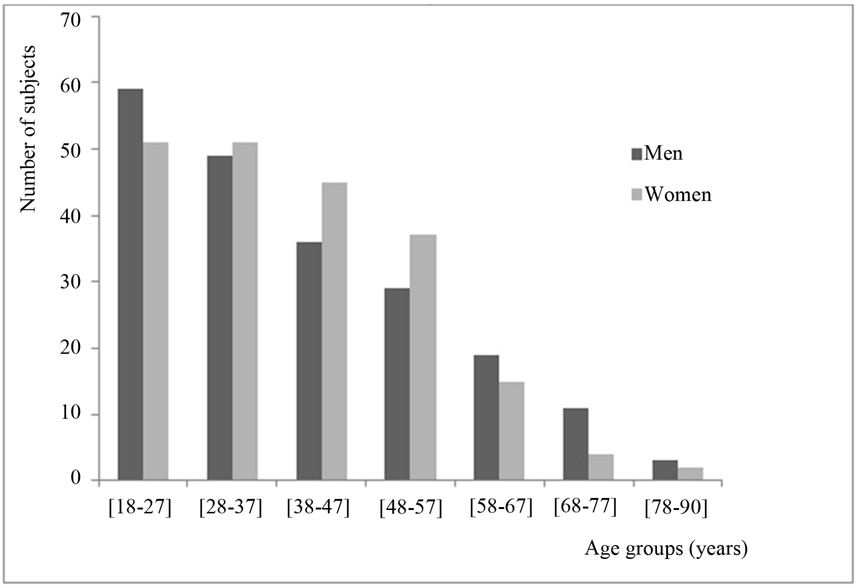

Figure S1. Age groups by sex of subjects.