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REVIEW ARTICLE

LUNG FUNCTIONS WITH SPIROMETRY : AN INDIAN PERSPECTIVE-II: ON THE VITAL CAPACITY OF INDIANS

M. B. DIKSHIT*, S. RAJE AND M. J. AGRAWAL

Department of Physiology,
MIMER Medical College,
Talegaon, Dabhade Dist. Pune – 410 507

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Abstract : Spirometry has been used in India since 1929 to evaluate vital capacity. The mean value for this parameter has changed slightly for the better over about eight decades. It is currently recorded at about 21.8 ml/cm height for males and about 18 ml/cm height for females, the difference between the two sexes being statistically significant throughout the period studied. The vital capacity reaches its peak at about 30 years of age in both Indian men and women and declines there after. There is no significant statistical difference in the vital capacities of subjects from different regions of India. Composite regressions have been generated for use as reference equations for estimating. Vital capacity of Indians is lower than that of Caucasians, but the age related decline is much greater for Caucasians.

Key words : regression equations for VC spirometry vital capacity

INTRODUCTION

Hutchinson, a London surgeon, in 1846, in his classic treatise "*On the capacity of lungs and respiratory functions*" introduced the concept of spirometry. He suggested that vital capacity might be a good indicator of the functional status of the lungs. Hutchinson, however, credited a Physiologist of earlier years, Borelli (1679), for being the first person to attempt measurement of 'quantity of air received by a single inspiration' (1). Measurement of vital capacity was used during the First World War for assessing fitness of military personnel, particularly aircrew for the Royal Air Force (2, 3). The Indian perspective was first presented to the Indian Science Congress in 1929 by Major General SL Bhatia of the IMS, the then Professor of Physiology, and Medicine, and the Dean, Grant Medical College, Bombay. Elanor Mason from Madras (Chennai) first reported in the Indian Science Congress of 1932 the data of lung functions for Indian women. From the 1950s onwards, rapid development of sophisticated measuring devices has refined the measurement methods.

*Corresponding Author : E-mail : mohan_dikshit@hotmail.com; Tele. Off. : (02114) 227938; Extn. 221; Resi. (020) 25657307

Principles and methods of measurement

Volume of a gas in the lungs is separated into compartments: Volumes and capacities (two or more volumes). Hutchinson had correctly designated these as a *"displaceable"* entity, (eg. the vital capacity), and an *"immobile"* portion (which remains behind in the lungs as the residual volume). The former is evaluated using spirometry tests, while the measurement of the latter requires special methods such as helium dilution, nitrogen washout, or plethysmography.

Spirometry recording may be either static or dynamic. During the latter the subject breathes out (or in) maximally under a time stress, with the recording made at a kymograph speed of 20 mm/sec. Dynamic spirometry is mainly used in the diagnosis of obstructive lung disease. The essential parameters obtained from this record are the Forced Vital Capacity (FVC), Forced Expiratory Volume 1 sec (FEV_1), the FEV_1/FVC ratio. The Maximum Mid Expiratory flow (MMF or $FEF_{75\%-25\%}$) may also be measured. Static spirometry, recorded at a slow speed (usually 2 mm/sec), measures vital capacity, also called Slow Vital Capacity (SVC), and other volumes and capacities.

There are two basic types of spirometers: wet (water sealed) spirometers, and dry bellows/rolling seal/wedge spirometers. The main drawback of water sealed spirometers has been the resistance to airflow generated by the system as a whole. Over the years, this problem has been suitably overcome, and with due care, dependable measurements can be made using such a spirometer. These are helpful in initiating the physiology student into lung function measurements. Dry spirometers are more convenient to use, generate less resistance to flow, and are relatively easy to maintain.

Basically, spirometers measure volume against time. Most modern versions of the instruments however make use of the pneumotachograph to *integrate* the flow generated to describe the Maximum Expiratory Flow Volume curve (MEFV) (flow vs volume), or if the inspiratory effort is also included, the FV loop. From this curve, FVC, FEV_1 and other relevant information such as the peak expiratory flow rate, $Vmax_{50\%}$ and $Vmax_{25\%}$ are measured. The latter two, along with the MMF are considered good indicators of air flow through small airways (<2 mm internal diameter). Simultaneously, a forced expirogram is traced on the recording paper. The computerized pulmonary function test machines are examples of this type of measurement device. It is mandatory that spirometers are calibrated regularly using calibration syringes.

For the expiratory effort to be acceptable, the criteria listed in Table I need to be fulfilled (4, 5). The observer must ensure that interpretation of the test result is made only after reviewing clinical data along with the graphic record, and the printed numeric result sheet.

At least 3–5 'satisfactory' efforts need to be recorded. In our laboratory, we accept 3 satisfactory curves with FVC values within 5% of one another, and use the best of these efforts (highest FVC). One may also

TABLE I : Criteria for a satisfactory effort for recording a forced expiratory spirogram.

1. Maximal inhalation before start of test.
2. Satisfactory start of exhalation as shown by i. Evidence of maximal effort; ii. no hesitation during the expiratory effort; iii. No cough or glottal closure during the first second.
3. The effort should last for a minimum of 6 seconds, or a plateau with a change in volume of less than 40 ml for at least 2 seconds towards the end of the effort
4. No evidence of leak.
5. No evidence of obstruction of the mouthpiece.
6. Nose clip may or may not be used while making the FVC effort, but must be worn for the SVC measurement.

use the record in which the sum of FVC and FEV_1 is the highest It is imperative that while evaluating an expirogram, the exact point on the graph at which expiration begins is accurately determined. Sometimes, spirograms of unsatisfactory/ inadequate efforts may also provide useful clinical information, and these need not always be discarded for clinical assessment if a 'satisfactory' record cannot be obtained (6).

Standard parameters from spirometry recording

Vital capacity, Forced Vital Capacity (VC, FVC), the Forced Expiratory Volume at the end of 1 second of expiration (FEV_1) and FEV_1/FVC ratio are the basic parameters required for assessing lung function. FVC is the volume of air that is breathed out as fast as possible while making a maximal expiratory effort after a maximal inspiration while the VC is the maximum volume of air breathed out after a maximal inspiration (no time stress).

In formal subjects, the FVC is marginally lower than the VC, especially in the elderly. This may happen because (i) there is earlier onset of dynamic compression of the airways, which occurs as a result of reduction in functional elasticity of lung tissue in the elderly, and (ii) resistance to airflow in the larger airways is likely to be enhanced by turbulence generated by the FVC effort. These effects are exaggerated in patients with obstructive airways disease. It has been recently suggested that the FVC manouevre may be modified so that after a maximal effort lasting for about 3 seconds, the expiration is made more relaxed. (6). This does not alter spirogram quality, and is better tolerated by the elderly, and also by the patients with moderately severe to severe obstructive airways disease. Chances of syncope during the forced expiratory manouevre are reduced. The effort yields higher VC values (7). Effect of bronchodilators could be better elucidated. A possible disadvantage of this technique may be the lowering of criticality of dynamic compression of diseased airways.

In this review, we have focused on VC (FVC) data of healthy Indian subjects. Various statistics had to be used for treating data obtained from published papers to (a) calculate VC over the years (from 1929 to date) from various available data, (b) see the distribution of VC with age and height, (c) compare VC in different age groups, and in subjects from different regions of the country, using the Kruskall-Wallis test for independent samples, (d) generate common regression equations for Indians, (e) generate isobars for estimating VC over a range of age and height, and (f) compare VC of Indians and Caucasians.

VC/FVC of Indians over the years

The recording of VC of Indians was first reported by Bhatia for men (2), and for women by Mason (8). Mean values for VC from various Indian studies since 1929 (2, 3, 8–37) expressed as VC/cm height, are given in Fig. 1. Over the years there has been a slight, but insignificant increase in the parameter in men. There has also been an increase in the VC of women. The extent of this increase is less than in the males. The average value of FVC/VC for males and females may show changes with time

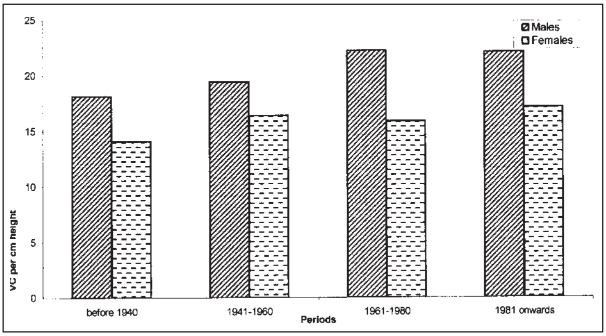

Fig. 1 : VC (ml/cm ht) is plotted for Indian males and females from 1929 onwards, in epochs of 2 decades. The values were calculated from various published papers given, in references.

because of (i) better recording equipments, (ii) improvement in the nutritional status of the average Indian, and (iii) possible effect of gradually increasing environmental pollution over the last eight decades or so. The first two factors would be expected to help increase the VC over time, while the latter would probably contribute to its reduction. Almost all the spirometry studies from 1929 onwards referred to in this review have been conducted in large cities where lung function parameters may have been adversely affected by the increase in environmental pollution over time. Different methods of measurements may also have influenced the outcome. For example Rao et al. (3) made measurements on supine subjects. The VC reduces in this posture. The overall effect seen is likely to be as result of an interaction of various factors given above. It is however near impossible to comment critically on these issues. At all stages, the VC of Indian men has been significantly greater than that of women ($P<0.01$).

VC as affected by age, height and sex

VC data for children (refs. 13, 38–46) and adults against age and height is plotted as a scatter diagram (Fig. 2). The VC increases in males and females, rapidly and almost linearly with age to about 18 years. A baby is born with the full compliment of airways, but the alveoli keep on increasing in number until about the age of 8 years. Thereafter the increase in alveolar size contributes to the increase in lung volume. By this assertion, it would be expected that there is a sudden acceleration in the increase in VC after this chronological landmark has been reached. The lower limit of age in a majority of the studies concerning children in this review is >7 years and hence if at all such an increase in VC does occur, it is not seen here. VC is also clearly greater with height.

The decline in the ventilatory capacity of the lungs has been reported to start around the twenties (47). This has been attributed to reduction in elastic recoil of the lungs, and early closure of the airways. The Total Lung Capacity (TLC) however

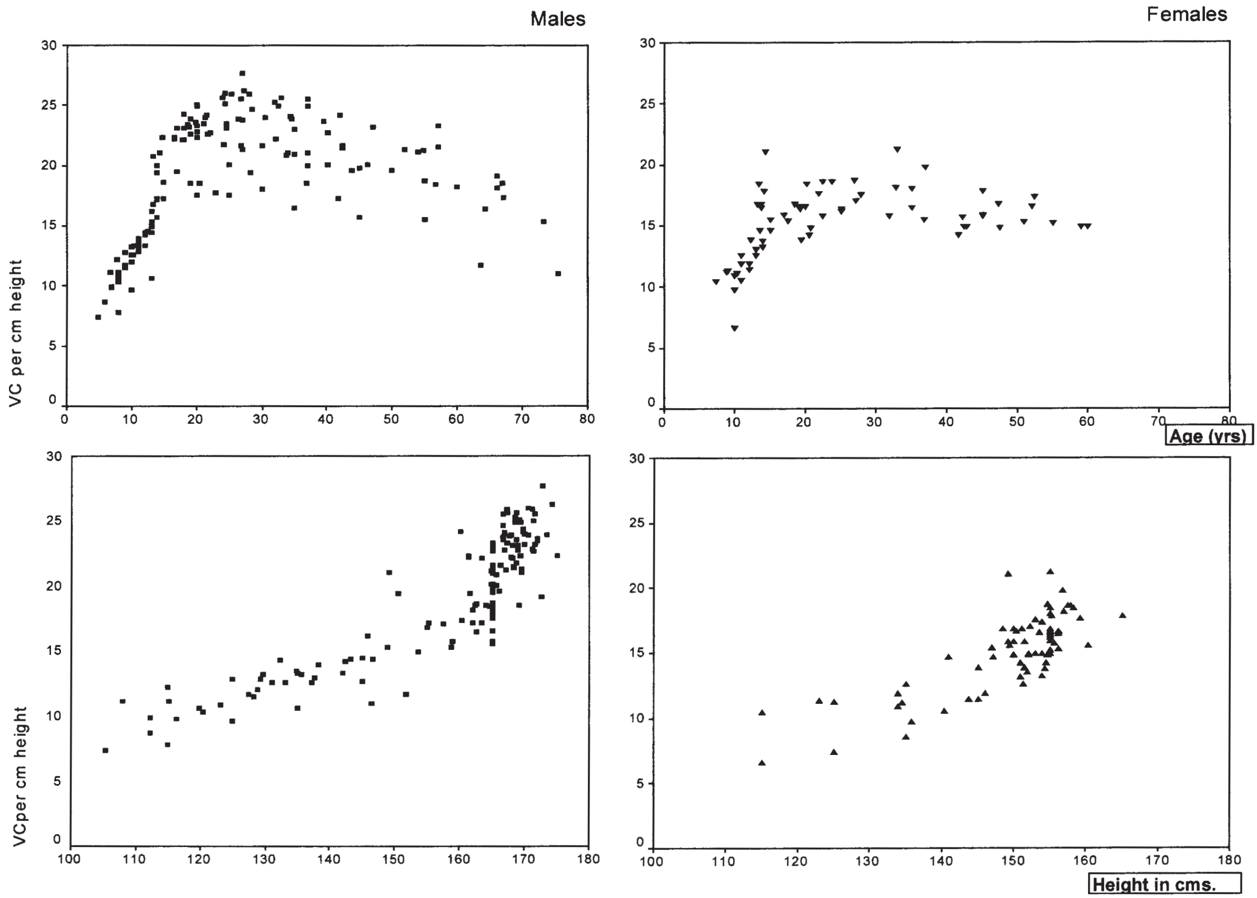

Fig. 2: Scatter diagram depicts relationship of VC with age, and height for Indian and females.

does not change upon aging, while the residual volume increases. This indicates that lowering of inspiratory muscle strength with advancing age is not a significant issue. It has also been suggested that after about 20 years of age, even after maximum somatic height is attained, the VC continues to increase for a few years more. This has been attributed to an increase in muscle mass (48). Some of the more prominent Indian studies have suggested that age related decrease in VC starts at about 40 years, and these changes become pronounced after 50 years (16, 23). The subjects of the latter study were active military personnel. Others have suggested that lung functions start to decline in both men and women by the 30s (26), and mid 20s (29). In women the decline is more, possibly because repeated pregnancies reduce abdominal muscle tone (16). This is likely to result in settling of the diaphragm at a lower level, limiting its excursion, and in reduction of expiratory effort by abdominal muscles.

To get an insight into the mean age at which the age related decline in VC starts, we calculated the mean VC values from various available data for 2-year epochs starting at age 18 years. The VC of both males and females increased steadily up to about 30 years of age, and then started to decline. The data for women above 45 years were inadequate, and hence have not been included. The heights of the adult subjects in different age groups were not significantly different. The contention that even if somatic height reaches its zenith, the VC continues to increase with age over the following few years (48) is substantiated by our deliberations. It has also been pointed out that after adult height is reached, the chronological age at which decline in lung function starts is varied. This accounts for the difference in the age at which such changes are noted. It may not explain as to why persons having the same height may have different VCs.

The study of the effect of aging on lung functions is handicapped by the fact that Information available in various studies pertains to different types of subjects in different age groups. The equipment and technique used for recording, and other factors which may influence recording, are usually varied. This is likely to confound the interpretations of results. Ideally, the same cohort of subjects should be tested and followed up over a number of decades in the same laboratory to obtain the proper perspective on a permanent basis for a population.

At any given age, the VC is positively correlated with height. The relationship is clearly illustrated in Figs. 2 and 3. From Fig. 3 it is seen that the VC is more in those subjects who are taller. This may be explained by the fact that taller individuals have more number of alveoli, and hence the volume capacity of their lungs is more (49). From the regression equations we have developed (Table II), it is seen that height wields greater influence on VC between 18 and 40 years of age in males as well as the females. On the other hand in adolescent males, it is the age that takes precedence.

VC of boys is expected to be more than that of girls even in the pre-adolescent age because boys are assumed to be physically more active. (39, 41, 42). After puberty the boys have ascendancy. The VC values for girls and boys as obtained from the reviewed literature were compared for below 13 years (the usual age of adolescence), and 13–<18 years. Below 13 years, the VCs for boys and girls were similar (12.5 ± 2.5 and 11.3 ± 1.6 ml/cm ht respectively, NS) but with adolescence, the boys developed a much higher capacity (20.4 ± 2.6 ml/cm) while it was 14.9 ± 3.4 for girls (13–18 years) ($P<0.001$ for boys vs. girls). The VC of adult females was significantly lower than that of adult males as expected ($P<0.001$). The reason for this sex difference has been attributed to greater inspiratory muscle strength of males. But this accounts for no more than about 4% of the total difference of about 20%. Males have more number of alveoli per unit area as compared with females, and their alveoli are larger and have greater compliance (50) Also, after the adolescent growth spurt, epiphysial fusion occurs earlier in girls. This results in a limitation of age related increase in the VC in girls after adolescence, while in males the VC continues to increase well into the twenties (51).

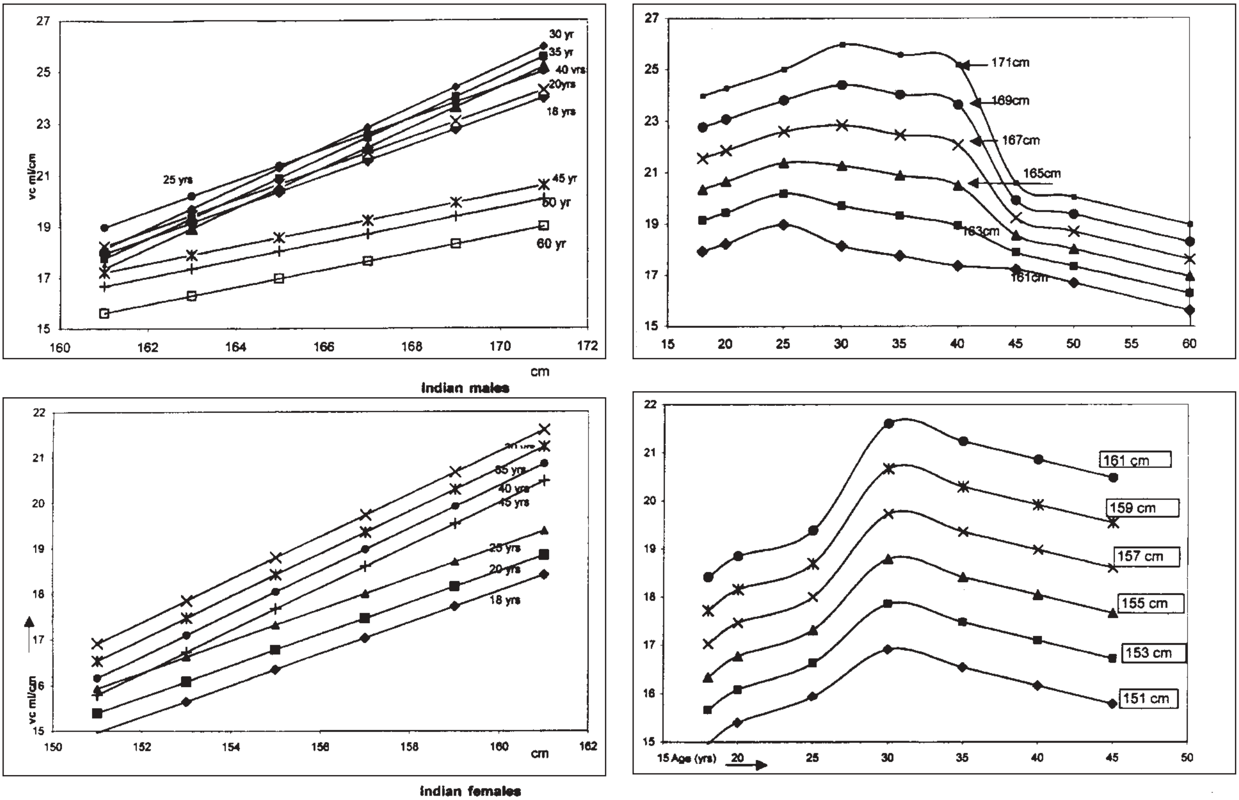

Fig. 3 : Shows isobars for depicting VC for varied height (left side) and age (right) of males and females. For females, upper age limit is 45 years. The graphs were constructed using regression equations derived for Indian subjects (Table II).

Composite regression equations for VC

This review encompasses studies from the North of India (11, 13, 15–18, 20–23, 27, 28, 31, 32, 35, 39–41, 42, 44, 45), from the South (8–10, 14, 24, 29, 34, 46), from the West (2, 12, 26, 30, 33, 37, 42). Most authors who have contributed to lung function tests in Indians advocate separate regional regression equations for estimating various pulmonary functions, with possibly ‘ethnicity’ as the factor affecting the results. However the concept of ethnicity is neither simple nor precise, and pertains to shared social background, traditions, culture, and dietary habits which lead to a sense of belonging between groups (52). With considerable intermix of the population, it might be difficult to exercise such regional biases. Also, in each region there is likely to be a considerable degree of variation in the characteristics that form a particular ‘ethnic’ group. There has been no serious attempt to statistically compare VC values in different regions of the country in order to establish that there are indeed significant regional differences. It might be better then to generate a composite regression equation for use for the Indian population as a whole. Cotes et al (53) combined data of British, North American and North Western European subjects to develop a combined regression equation. Their subjects as per the considered meaning of the term “ethnic’ were different. Using the Kruskall-Wallis test we compared the VCs of subjects from the northern, eastern, western and southern regions of the country. The age range considered was 18–40 years. The mean VC values for these four regions corrected to a standard height of 165 cm [corrected as per Cole (54)] were not significantly different at the 1% level. Therefore, we have considered the population in which various VC studies have been done, as homogenous, and developed regression equations (Table II), which may be used on an all India basis for estimating VC/FVC. The data for age beyond 60 years in males and 45 years in females is relatively scanty in Indian literature, particularly for females, and has not been addressed.

TABLE II : Regression equations: FVC/VC expressed as ml/cm height.

Age (years)	*Males*	*Females*
<13 yr	–5.69+0.087 Age + 0.131 Ht	
13–18	–8.48+0.53 Age + 0.126 Ht	
>18–<27	–81.81+0.15 Age + 0.603 Ht	–41.56+0.22 Age +0.345 Ht
28–<40	–105.42–0.078 Age + 0.782 Ht	–51.67–0.075 Age + 0.469 Ht
40–60	–32.06–0.071 Age + 0.336 Ht	

The rate of decline of VC : We have used these equations to construct Fig. 4 for standard height of 165 cm for males (age range 25 to 60 yr) and 158 cm for females (age 25–45 yr). In the males, the decline in VC is about 0.1 ml/cm ht/year. The rates of decline in VC as calculated from various data available on healthy subjects on the subcontinent, is widely varied as reported for Indian males. Jain and Gupta (16) reported that VC does not start to decline until after 40 years of age. On the other hand, when data from Jain et al (18) was critically analyzed, it was seen that a similar population tends to reduce their VC at about 11 ml/yr. In natives of the North-Western part of the subcontinent, the calculated rate of decline was only about 6.6 ml/yr (27). The decline in VC as estimated for ht 165 cm from another study in Delhi (34) works out to be about 25 ml/cm ht. From the western India, it is about 18 ml/yr (26). Fig. 4 therefore represents the aggregate of decline of VC for Indian subjects with advancing age. The reduction in this parameter in western subjects has been reported at about 25 ml/year (48). The rate of decline for Indians is much lower than that for Americans (55) and Europeans (56), and it stands at about 26 ml/year as seen from Fig. 4. By the 6th decade, this difference in the pattern of decline of VC, brings the Indian value closer to that of the Caucasians. It is conceded that the regression equations from refs 55 and 56 used to calculate VC are taken as representative samples for calculating Caucasian values of VC for males and females. The larger picture may be slightly different. It is also interesting to note that if the American males have higher VC than the Europeans, the European females do better than the Americans.

In Indian women between 25 and 40 years, the rate of decline of VC at about 8 ml/cm/year is much lower than that for

Caucasians who decline steadily at about 23 ml/cm /year. The VC of Indian women therefore is at par with the Caucasian values by the fifth decade; in fact they are higher than that of the Americans (Fig. 4). The reason as to why this happens is not clear. It is interesting however that the disadvantage of a relatively lower VC of Indians, male and female, is slightly offset by a lower rate of decline. It is difficult to say what happens in the later decades because of the paucity of data pertaining to older Indians, particularly women.

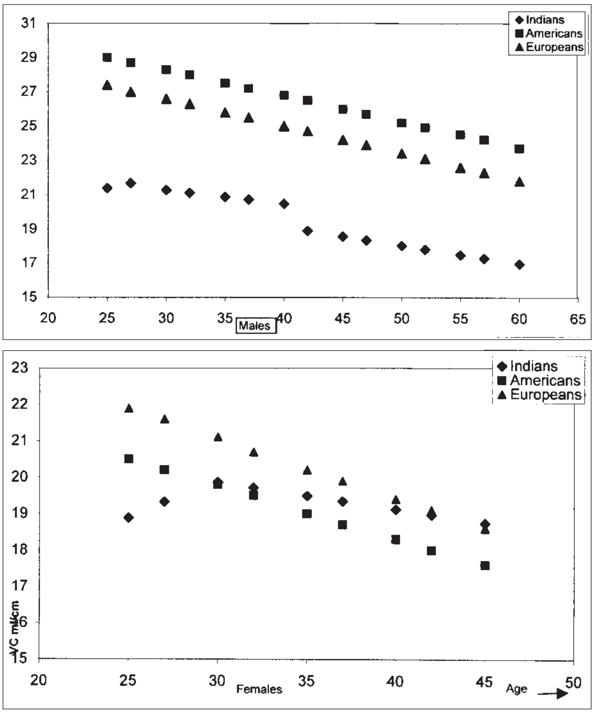

Fig. 4 : Decline of VC with increasing age in Indian subjects as compared with Americans (ref. no. 55), and Europeans (ref. No. 56).

The decline in VC of older women may be hastened after menopause in an unknown manner. The cumulative effects of pregnancy, and a general decline in physical fitness at about that age may be responsible. Given the circumstances, these factors may take a bigger toll of lung functions of Indian women.

The biggest draw back on arriving at any firm conclusions on the issue of decline in lung functions with aging is the fact that none of these studies are a longitudinal follow up of a single cohort of normal subjects over a span of time.

Ethnicity and VC

It is been generally opined that VC of Indians is less than that of Caucasians (16, 23, This is demonstrated for males in Fig. 5. VC of Caucasians was obtained from refs. 3, 25, 47–49, 53, 55, 56–63. A number of reasons may be given for this observation: a) Caucasians are physically more fit. b) They are taller, and hence have larger lung volumes. While discussing ventilatory capacities of tropical populations, Patrick (25) had brought out that for a given stature, Europeans had a greater trunk size as compared to Blacks. This difference was calculated to give a 13% increment in thoracic volume of Europeans. It is possible

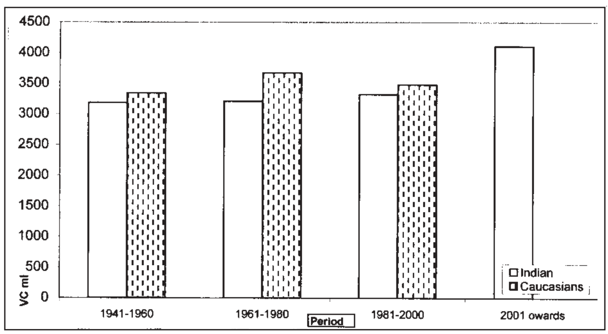

Fig. 5 : VCs of Indian males and Caucasian males. Data for the latter was obtained from ref. nos. 48-50; 58-63.

that the same analogy holds true for Indian subjects as compared with Caucasians. It was not possible to treat data for Indian women in a similar manner.

Environment and VC

VC/FVC has been related to physical fitness. Military personnel are expected to be more physically fit, and properly nourished as compared with civilians, and should therefore be endowed with higher VC. The VC of military personnel (20, 23, 28, 32) was observed to be significantly greater than that for civilians (23.6 ± 1.6 ml/cm ht vs 18.8 ± 5.0) in the age group 19–30. In fact international level Indian athletes have a VC which is highest of the lot at 26.2 ml/cm ht (20). High altitude natives of the Himalayas have very high VC. Patrick (25) standardizing VC for 165 cm and 35 years, has reported a value which works out to around 31 ml/cm which is much higher than that found in Europeans. Apte’s Ladhaki soldiers (57) have a (F)VC which is 30.2 ml/cm ht. In both the reports, the subjects concerned were domiciled natives of high altitude, living and working at altitudes of 15000' and beyond.

Pollution may adversely affect lung functions of subjects. Udwadia et al (26) whose subjects were assessed in Mumbai, suggested that lung function parameters they recorded were likely to be adversely influenced by the high level of pollution in the metropolis. It might to interesting to measure VC of contemporary Delhi citizens, and compare the results with those reported in the similar studies from Delhi in the mid 60s (15, 16, 17, and 18). Interestingly enough, a comparison of VC of men 27 years and 55 years of age in 1969 (17) and 1995 (34) recorded at the same laboratory in Delhi in healthy Delhi residents, showed a value of 19.5 ml/cm ht and 21.2 ml/cm for 55 year olds. The higher value was recorded in 1995. For 27 year olds, the mean VC was 24.6 ml/cm and 25.5 ml in 1969 and 1995 respectively. The 1969 recordings were made using a water seal spirometer, while the 1995 measurements were made using a computerized system.

Uses of Spirometry

Spirometry may be used for (i) enhancing basic physiological knowledge, (ii) early detection and diagnosis of pulmonary disease, (iii) assessment of rational therapy; and (iv) research.

Lung disorders are generally classified as those with airflow limitations (obstructive), those with volume restriction (restrictive), and those with a combination of obstruction and restriction. The data may be categorized as being consistent with normal Spirometry functions (normal FVC and FEV_1/FVC ratio), obstructive pattern which may have a normal FVC but a low FEV_1/FVC ratio, or a low FVC with a low FEV_1/FVC ratio) and restrictive (low FVC with normal or high ratio). Generally, the diagnosis of obstruction in the airways using Spirometry is easily made when, in the face of even a normal FVC (VC) the FEV_1/FVC ratio is lower than normal. The gold standard for diagnosing restrictive lung disease still remains the measurement of total lung capacity using helium dilution or plethysmography methods. A low FVC may result from an obstructive or a restrictive lung disorder. In the absence of airflow obstruction, it has been suggested that a low FVC with normal or high ratio may be diagnosed as a restrictive defect on the basis of spirometry alone (64). It is obvious that VC must be recorded with some other parameters such as the TLC, FRC, diffusion capacity of the lungs, to obtain an insight into lung functions. However when lung volume is affected, VC is by far the best test to monitor lung functions (4).

Apart from the clinical setting, VC/FVC have been used as research tool to investigate effects of environmental stresses on body physiology. For example, an incremental increase in FVC during graded application of lower body negative pressure also reflected a graded decrease in central blood volume (65), while a decrease in FVC was noted during head down tilt experiments used to simulate sub-gravity situation of space flight (66).

Interpretation of lung function test results

This usually involves comparing patients' values with suitably selected reference values from population studies. All pulmonary function tests are diagnostic, quantitative measures, but they cannot detect a defect unless the lesion is big enough to produce a reduction of the measured parameter well below normal. Ideally, baseline values for an individual should be available because a change from a patient's baseline data would be a better indicator of altered lung function rather than comparison with the lower limit of population standards for that age and height and sex. For example, an individual may have a baseline VC which is well above the 'normal' as per available norms. If this individual develops significant degree of disease condition, then his pulmonary function will decrease. And yet the new level may be well above the stipulated lower limit of normal as per norms, eliciting a "normal" report. No single test is sufficient to give all information for every patient, nor are all tests necessary for management of every patient. It is imperative that interpretation of the test is based only after carefully viewing graphic as well as numeric results. Spirometry is basically meant to support a carefully made clinical assessment of the patient.

Limitations of spirometry testing

Difficulties in standardization of the technique, the quality and limitations of the "equipment used for the test, and the fact that the test gives only limited information are some of the inherent drawbacks of spirometry testing. Computerized spirometry raises questions about reference values, and criteria for interpretation of the tests Daily calibration of the equipment is required. The acceptability of values for degree of reversibility of change in air flows in a patient of obstructive disease has always been controversial. In spite of all these drawbacks, spirometry testing continues to be in the forefront for diagnosis and follow up of patients with lung disease, particularly obstructive, and to some extent, restrictive lung disease.

Conclusion

Spirometry testing is a useful tool for assessing lung functions. It is necessary to realize that these tests are only an adjunct to clinical assessment and diagnosis, and interpretations of the tests must be made in that light. VC/FVC values are useful in determining the extent of abnormality involving alterations in lung volumes. There are many pockets of information regarding lung functions of Indians from various laboratories in the country. There is however a need to make an organized attempt to study lung functions of designated cohorts longitudinally, starting in childhood, over a number of decades, to establish norms for the Indian populations. This needs the promotion of a nationwide project, controlled by a single investigator from a designated laboratory so that all aspects of the investigation are standardized. This laboratory should then recruit other regional laboratories to conduct the study under its direction. The project will have to be passed down the hierarchy of investigators if need be. In practice, this may be difficult but not impossible. Alternatively, a central investigator may simultaneously direct data collection in multiple laboratories. Here standardization of equipment, technique of measurements, and training of the personnel involved will have to be carried out by the principal investigator.

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