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REVIEW ARTICLE

LUNG FUNCTIONS WITH SPIROMETRY : AN INDIAN PERSPECTIVE-I. PEAK EXPIRATORY FLOW RATES

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Abstract : Peak expiratory flow rate is an effective measure of effort dependent airflow. It is relatively a simple procedure, and may be carried out in the field using portable instruments. The average PEFR of healthy young Indian males and females is around 500 and 350 lpm respectively. The PEFR reaches a peak at about 18-20 years, maintains this level up to about 30 years in males, and about 40 years in females, and then declines with age. Common regression equations for Indians enveloping major studies from various parts of the country have been formulated. Indian PEFR values compare favourably with other ethnic groups such as Americans and Europeans.

Key words : FVC PEFR regression equations standard values

Peak Expiratory Flow Rate (PEFR)

PEFR as a measurement of ventilatory function was introduced by Hadorn in 1942, and was accepted in 1949 as an index of spirometry (1). By definition, it is "The largest expiratory flow rate achieved with a maximally forced effort from a position of maximal inspiration, expressed in liters/min (BTPS) (2).

The PEFR is an effort dependent parameter emerging from the large airways within about 100–120 ms of the start of the forced expiration (2, 3). It remains at its peak for about 10 ms (1). It may be reliably recorded using portable equipment, and thus can be used in field studies. Even in normal subjects the values may be variable as the parameter is entirely effort dependent resulting in a high intra subject variability. Nevertheless it remains an effective tool for assessing a limited aspect of ventilatory function.

Measurement of PEFR : The Wright's Peak Flow Meter (Air Med, UK) has been used universally to measure PEFR. The dial range is 0–1000 litres/min (lpm) though the ATS recommends a range of 100 lpm to

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< 850 lpm (2). It is an accurate, rugged, and portable instrument. More recently, a number of Mini peak flow meters have been introduced (range usually 60–800 lpm for adults and 60–400 lpm for children). The more popular ones available in India are the Vitalograph mini (Vitalograph UK), Assess (Healthscan USA), and Clement Clerk Mini Wright (Clement Clerk UK). Some pocket versions are also available (LR Wright Pocket, Ferraris; LR Pocket peak, Micro Medical). All contemporary computerized pulmonary function test equipments record the PEFR as a part of the flow volume curve. Most of these incorporate the pneumotachograph as the basic transducer. Other measuring devices include rolling seal dry spirometers, and the whole body plethysmograph with a Fleisch pneumotachograph. Unlike the volume measuring devices, it is generally difficult to calibrate flow measuring ones. Fan airflow generators with rota-meters, which may or may not be very accurate, have been helpful. Using a gravity influenced piston and cylinder type flow calibrator, various types of PEFR measuring devices have been evaluated (4). The error produced by the instruments varied from 0–26%. The Mini version of the Wright's peak flow meter was the least consistent. This instrument has however been used to measure PEFR for physiological studies, and found to be suitable (5, 6). It is suggested that for research oriented measurements, the easy to handle Mini peak flow meters may be avoided, and if used, are best tested against a standard, well used Wright's peak flow meter before being accepted. The frequency response of the measuring device should be within ± 5% up to 12 Hz, with an accuracy of ± 20 lpm. The resistance in the system should not exceed 2.5 cm H_2O/liter/sec (2).

For making the measurement, the subject/patient breathes out (blows out; blasts out) maximally into the peak flow meter after having taken a maximum inspiration. The basic requirements and precautions for an acceptable effort are similar to those required for making a forced expirogram measurement (7). As PEFR is achieved after 100–120 msec of initiating a maximal expiratory effort (3), the expiratory effort need not continue up to residual volume. At least 5 efforts must be made, of which 3 should fall within 10% of one another, as against the FVC manouevre where a difference of 5% between two efforts is the minimum acceptable (2). The best of the three efforts is recorded. For research measurements, the mean of three acceptable values maybe taken. This flow rate may show a diurnal variation of about 7% in the morning and 3% in the evening as estimated by measuring the variation in the amplitude % of the mean (8), while pollution in the atmosphere can also contribute to this effect (9).

The PEFR can not be obtained from the forced expirogram that is recorded on a mechanical spirometer. The parameter which can be calculated from this graph that has some proximity to PEFR is the $Vmax_{200-1200\ ml.}$, or its equivalent, the volume 80 msec PEF, the flow rate determined from the volume-time curve using a 80 m sec segment. It has been suggested that PEFR recorded using a peak flow meter (open circuit) may not be corrected to BTPS. But the ATS (2) recommends otherwise. In our laboratory, we make the BTPS correction.

Normal values: Most PEFR measurements reported in Indian literature have been carried out using Wright's peak flow meter. The technique of obtaining a successful attempt by the subject at giving the test is less exacting than that required for recording the forced expirogram/flow volume curve, and most workers quoted would have been reasonably successful in getting the best out of their subjects while recording PEFR. This makes comparisons of different results more possible. Singh and Peri (10) have tabulated PEFRs obtained from a number of Indian studies. From this it is seen that young Indian males have a PEFR of about 450-550 lpm, while in young females it is a little lower (320–470 lpm). A larger sample surveyed later (1) also brings out similar results. In one of our own studies (11) we have reported that healthy young medical students (mean age 18.3 yr) had a PEFR of 587 lpm, the slightly older ones at 24.4 yr were at 541 lpm, and 38 year olds recorded 548 lpm. The 10 Army athletes (mean age 25.5 yr) had a PEFR which was also 587 lpm. More recently, while studying effects of bronchodilator aerosols in left handers and right handers, we found that the mean pre-treatment PEFRs of 13 healthy male medical students (mean age 22 yr; height 171.6 cm) recorded from acceptable flow-volume curves on a Schillers Computerised Pulmotest equipment was 9.2 lps (550 lpm) (12). Mechanical instruments which generate some degree of resistance to airflow may be expected to record slightly lower values of the flow rate as compared with computerized equipment. A review of values obtained using both types of equipments does not substantiate this assumption. On the other hand, using Morgan computerized equipment, to generate flow volume loops, a relatively low mean PEFR of only 474 lpm has been reported in 20 yr old male athletes (13). It is difficult to explain this observation made by using a state of the art recording device when a value of around 550 lpm in healthy young non-athlete males were reported from the same region (10). The latter used Wright's Peak Flow meter for making their measurements.

Data from Indian studies (ref nos 1, 10 to 31) which have looked at PEFR in males and females has been plotted in Fig. 1. All subjects concerned were healthy, mostly non-smokers. From the figure, it is seen that the males achieve a peak at about 20–25 years of age, maintain this level up to about 30 years, and thereafter their PEFR starts to decline. Females appear to achieve maximum flow a little before 20 years, and appear to maintain that level for almost 2 decades. The expected decline with age begins at about 40–45 years. The relatively prolonged maintenance of peak values in females seems to coincide with their reproductive life. Prevalence of female sex hormones may be responsible for this phenomenon. That female sex hormones affect airway behaviour is known (32). Others also report that males reach their highest PEFR by about 25 years, while the females achieve it a earlier at about 20 years of age. (33). The beginning of decline of lung function parameters has been reported to begin at about 30 years of age in both males and females (26), around 25 years in males, and 21 years in females (33) while others concluded that it begins at about 40 years (34, 35), and becomes obvious only after 50 years of age. The latter two studies have not reported PEFR measurements, but take into account FEV_1 which is an effort dependent volume.

Age and height together are often used to determine PEFR in regression equations. Effect of one on PEFR is influenced by the presence of the other. If a total population is considered, PEFR is distributed normally with age and exponentially with height. Hence it is difficult to combine both these parameters in the regression equation for prediction of PEFR for a wide range of age extending from childhood to late adulthood. Secondly, height in adults plateaus after a certain age. Thus one single equation to predict PEFR with both age and height as parameters encompassing extremes of the age range becomes complicated. Various statistical models have been developed to relate PEFR to age, height and weight of the subjects. These models have been linear, multiplicative, polynomial and proportional (36). However, only the linear model adequately explains variations in PEFR. We have used the pooled data to construct linear regression equations using age and height as the regressors for 3 age groups: < 20 yr, 20–60 yr, and > 60 yr. (Table I) Using these, we estimated PEFRs at the designated age groups, and compared these values with those obtained for the same age groups from various published data. (Table II). The PEFR values for estimated and actual data were quite similar, and the

TABLE I: Regression equations for males and females of various age groups. Linear model: PEFR = Constant (a) + ht cm*b + age*c. P denotes statistical significance at <0.05: *sig.; **highly sig.; NS not significant.

Age (yrs)			*Females*	*SE*	*Males*	*SE*	*P for (F)*	*P for (M)*
<20	Constant	a	–347.20	88.98	–801.42	147.75	**	**
	Height	b	3.99	1.06	9.59	1.78	**	**
	Age	c	5.49	5.09	–19.94	8.87	NS	*
20–60	Constant		–1072.47	508.48	–16.15.70	615.45	*	**
	Height		9.52	3.25	12.79	3.57	**	**
	Age yr		–0.43	0.43	–0.32	0.80	NS	NS
>60	Constant		2275.60	2166.96	–9253.03	0.00	NS	**
	Height		–9.77	12.15	51.32	0.00	NS	**
	Age		–8.19	5.47	18.9	0.00	NS	**

TABLE II: Mean±SD of observed PEFR values taken from studies in refs 10–31 are tabulated with PEFR values estimated by using regression equations given in Table I.

Age group	*Males*		*Females*	
	Observed	*Estimated*	*Observed*	*Estimated*
<20	308.1±135.0	298.4±135.6	273.5±98.8	251.9±101.7
21–30	544.1±37.5	535.7±43.0	371.3±38.7	395.2±4.9
31–40	525.5±37.5	528.9±25.1	334.7±51.2	372.7±16.6
41–50	485.3±52.8	571.5±23.2	338.1±58.7	396.2±50.9
51–60	442.5±33.3	455.3±19.9	336.2±51.6	356.4±26.9
>60	379.2±67.9	377.0±71.8	265.8±33.5	265.8±27.4

SEE for the estimated values were relatively low. This demonstrated that even though data from different studies across the country was used to generate these equations, there were almost no outliers. We are convinced therefore that these equations can be used to predict PEFRs in any part of India with reasonable accuracy. Other recognized studies from the West also use the linear model for their regression equations (37, 38).

PEFR of special groups: Peak flow rate is higher in fitter, healthier populations such as Armed Forces personnel, and athletes. Goyle et al (15) found a value of over 500 lpm in all their subjects between 19 and 42 years. Similarly, elite military athletes (national/international level; 27.3 yr; 174.2 cm) had a mean value of 620 lpm as against healthy non-athlete soldiers of similar age and height (593 lpm, (NS) (29). Military athletes in our study had lower PEFRs at 587 lpm at a mean age of 25.5 yr (11). All these measurements were made using the standard Wright's peak flow meter. It is surprising therefore that PEFRs measured in national level athletes (22) were 570 lpm for North Indian male athletes (24 yr), 538 for South Indian males (22.5 yr), and 403 lpm for international level women athletes (22.5 yr). All the athletes concerned were runners who are expected to develop high degree of cardio-respiratory conditioning. It is possible that the Wright peak flow meter used had offered more than the expected resistance which went unnoticed. In another study using flow volume loops recorded on computerized equipment (PK Morgan), the peak flow rates of college level athletes were relatively low for 19 year olds (473 lpm (13). The reason for this is not clear. Perhaps the degree of cardio-respiratory conditioning following athletic training was not well established at the time of recording. Even then, the values reported are lower than the average value of 550–590 for males of that age group (10, 11, 29).

High altitude natives (HANs) like the Ladhakis, are adapted to that environment over generations. Apte and Rao, (unpublished observations) (39) while recording MEFV curves in such subjects, noted that HANs and healthy lowlander soldiers acclimatized to HA (3400 m) had PEFRs in the range of 569 lpm and 616 lpm respectively (NS). As such these values were not particularly high, considering those reported in some of the studies quoted above. Also the authors have not given values measured in their subjects when at sea level with which to compare the HA data. However, their contention that the PEFRs were high at HA because of lowered airway resistance as a result of the thinner atmospheric air is interesting, and could be further elucidated. These authors argue that because of the special environmental factors at HA, a separate regression equation should be developed for HANs for use there. At this point of time this seems premature. The lowlanders and HANs have similar PEFRs. If a regression equation is developed for this parameter, it should be for all subjects who have acclimatized/adapted to HA. Also the height of the laboratory where the measurements will be made, must be pre-selected viz 3400 m in this case. The other possibility would be to establish the % increase in PEFRs of subjects at HA as compared with subjects at low altitude, and develop statistics accordingly for comparison. In the same unpublished data, the authors (39) point out that the effort independent airflows of the HANs are significantly greater than acclimatized low landers, and that this is a part of the adaptive phenomena that the HANs have undergone. There is a strong case here for generating a large amount of data on flow volume curves of HANs be they Ladhakis or Sherpas, and then develop regression equations for peak air flows, as also airflows from the lower part of the MEFV curve.

PEFR during pregnancy: PEFR decreases significantly in pregnant women (40). The decline begins in the first trimester, and reaches its lowest value towards the end of the 3rd trimester. The rate of decline is 4.8 lpm/month of gestation in the first trimester, and about 8.5 lpm in the later period. Lack of proper nutrition during pregnancy, anemia of pregnancy (Hb% <6-8 gm), and a reduction in overall muscle strength, are some of the reasons cited. Vital capacity increases slightly with pregnancy, mainly as result of reduction in expiratory reserve volume (41, 42). This factor in tact should help in an increase in PEFR rather than its decrease. The post partum recovery of PEFR takes about 8–10 weeks (40). It would also be worthwhile comparing PEFRs of well nourished, non-anemic women from a high socio-economic status with those from a low socio-economic status. Puranik et al (40) do not mention the socio-economic status of their subjects.

Western women did not show a reduced PEFR during pregnancy (32, 42). It has been suggested that a more effective force development in the respiratory muscles occurs because of realignment of the diaphragm during pregnancy in these women. There is no apparent reason as to why certain ethnic groups of women are genetically predisposed towards a better maintenance of their ventilatory attributes during pregnancy which is a universal phenomenon. The issue of PEFRs during pregnancy therefore needs to be investigated in its various aspects.

PEFR in children: Information on this aspect of spirometry in India is relatively wanting. Children, as also adults on many occasions, find the forced expiratory spirogram/flow volume loop difficult to perform. But even 4 year olds have been known to make successful PEFR efforts with the peak flow meter (16). Using some of the available regression equations, PEFRs were calculated for boys and girls having heights of 110 cm, 140 cm and 160 cm (adolescence) (Table III).

PEFRs of girls was found to be higher than that of boys in early childhood while during adolescence the trend reversed (14). But this is not in evidence in the other Indian studies for children having a height of 110 and 140 cm (5, 16), nor was there a gender difference found amongst Indian children domiciled in the UK (24). The gender difference (girls having greater expiratory flow rates) is evident when dealing with effort independent flows (32) rather than the effort dependent ones. Two studies on PEFR in children were reported from Delhi in 1997 (5, 46). It is interesting to note that the PEFRs reported in one (46) were lower than those reported in the other (5). Both studies, conducted by experienced workers, were carried out in carefully selected, healthy children belonging to similar socio-economic status and age

TABLE III : Comparison of PEFRs in children at three different heights as estimated by regression equations of various studies. The numbers in parenthesis are the reference nos. as they appear in the references list. For calculations for ref 5, ages considered are 8, 12 and 16 years.

Reference paper			*PEFR lpm*					
			For ht 110 cm		*For ht 140 cm*		*For ht 160 cm*	
			Girls	*Boys*	*Girls*	*Boys*	*Girls*	*Boys*
1. Pande et al	1997	(5)	139	148	257	285	347	395
2. Parmar et al	1977	(14)	186	147	311	299	395	401
3. Singh & Peri	1978	(16)	116	130	266	280	366	380
4. Sitaram et al	2003	(21)	NA	176	NA	324	NA	424
5. Patrick & Patel	1986	(24)	NA	169	NA	296	NA	405
6. Sharma et al	1997	(45)	NA	NA	210	213	305	315
7. Mukhtar M et al	1989	(46)	NA	NA	NA	NA	396	416
8. Kasyap et al (High altitude natives)	1992	(47)	134	152	266	304	355	405
9. Chowgule et al	1995	(49)	131	174	253	340	340	370

groups. There was however a difference in the instruments used for making the measurements. Mini Wright's peak flow meter was used in one (5) while the PK Morgan computerized system was used in the other (46). Pande et al (5) have commented that different instruments used for measuring PEFR may account for the variation in values reported in different studies.

It has been opined that Indian children have lower PEFRs as compared with American white children (5). These authors attribute lower Indian PEFRs to relatively poor intra uterine growth. On the other hand, a study in Nottingham UK found no difference in the flow rates of Indian, Caucasian, and Black children (24), but the FVC and FEV_1s of European children were found to be higher by as much as 13%. Parmar et al (14) reported that Indian children whose heights and weights were comparable to American children, had PEFRs that were comparable. Similarly, Arab adolescents (47) had PEFRs similar to those reported in other studies (Table III) Therefore, ethnic differences do not appear to influence PEFR of children to any great extent as generally believed. Permanent residence at high altitude does not affect PEFRs of children. (48).

Factors affecting PEFR

A number of factors influence PEFR in normal subjects. Age and height are the obvious ones. PEFR is best correlated to height in children, even though other physical factors such as age and body surface area also correlate well (25; and Fig. 1). It has been suggested that ventilatory functions of normal subjects can be predicted better by using sitting height. This reduced racial differences in ventilatory functions, PEFR included, between Mexican-American, white, and black children and adolescents (43). However, a study in which PEFR was determined using both standing height and sitting height revealed that the latter does not refine the prediction of the parameter (36).

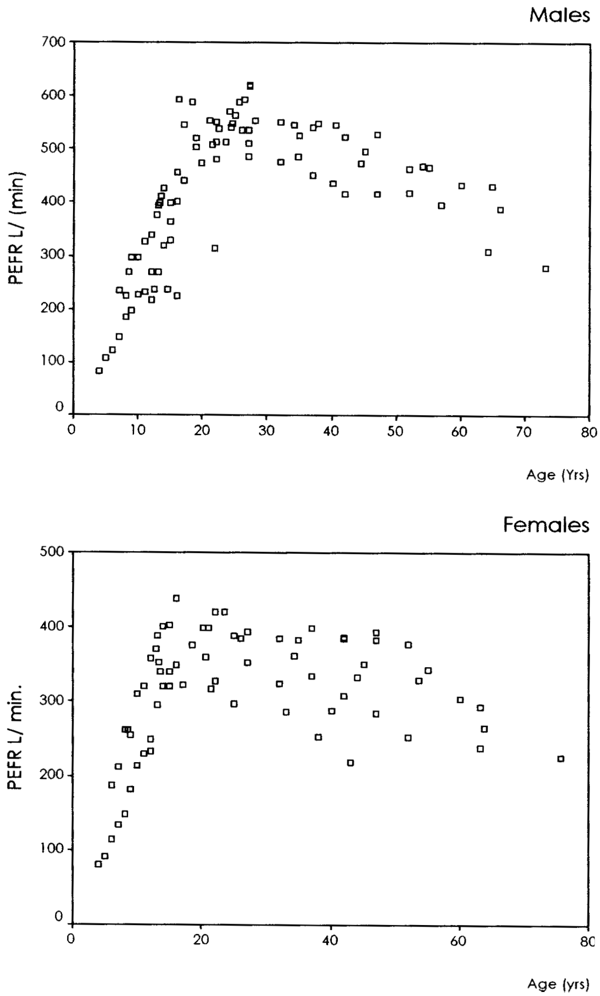

Fig. 1 : Distribution of PEFR (1/minute) in Indian males and females plotted against age (yr). Data obtained from references 10–31.

Apart from the differences between men and women attributed to greater muscular strength of men, and their airways diameter, which may be larger in men by as much as 17%, the female sex hormones are likely to influence airway behaviour (32). During pregnancy, the airways may also be affected by the fetal sex hormones. The mother's airways are less reactive if the fetus is a male(32).

Factors which have an adverse influence on PEFR are i. low socio-economic status, ii. overcrowding of residence, and iii. smoking (33). The second factor is often a reflection of low socio-economic status. PEFR is also influenced by various environmental factors during childhood, level of physical activity (33), and possibly by relatively poor intra-uterine growth (5). Other authors have also linked lower PEFRs to socio-economic status and under-nourishment (10). Many workers advocate that this fact should be taken into account while interpreting PEFRs of such people. It is however stressed that standards for spirometry be based on the data acquired in well nourished, healthy subjects, and should not include data from under-nourished subjects. If such subjects are found to record a low PEFR, then it should be reported as below normal, and the cause for the low value may be debated upon separately.

PEFR has been well correlated to maximum expiratory pressure which is a representation of respiratory muscle strength (44, 45). Exercise training increases the PEFR because of an increase in respiratory muscle strength.

Smokers are known to have a lower PEFR over all age ranges in both the sexes, but the difference between smokers and non-smokers becomes significant only in the fifth decade of life. Ferns et al (37) have developed two regression equations-one for healthy non-smokers which includes ex-smokers, and another one for persons without respiratory disease which includes both smokers and non smokers. From their

TABLE IV: (A) PEFR values are calculated for males ht 162 cm, females ht 154 cm. for various age groups, The regression equations used for making the calculations are given at the bottom of the table, using regression equations for Indians, Europeans and Americans (B) in order to elucidate ethnicity as a factor. The numbers in parentheses represent the reference numbers of studies quoted.

A

Age	*Indian*		*American*		*European*	
	Males	*Females*	*Males*	*Females*	*Males*	*Females*
25	448	383	504	374	541	397
35	445	379	480	357	515	379
45	442	374	455	340	490	361
55	439	370	430	323	464	343
65	289	240	406	306	438	325

B

	Ethnicity		*Regression Equations*
1	Indian (Present report)	Table I above	
2	American	(37)	M 4.73* ht (cm) – 2.46* Age (yr) – 200.32 F 2.96* ht – 1.71* Age – 39.19
3	European	(38)	M 6.14* ht (m) – 0.043* Age (yr) + 0.15 F 5.50* ht (m) – 0.030* Age – 1.11

data it is obvious that moderately heavy to heavy smokers have lower PEFRs after the age of 40 yr. Female smokers are at a disadvantage from the 3rd decade of life (33).

It has been generally believed that as an ethnic group, Indians have lower PEFRs as compared with Europeans and American whites. PEFR values for males and females of various ethnicities at a given age and height are given in Table IV. It is seen that Indian PEFRs are at par with those recorded in other ethnic groups. Malaysian aboriginal adult males (mean age 26 yr, ht 163 cm) had a PEFR of 475 lpm (50). Comparative value for Indian males of the same age and height as calculated from our composite regression equation is 488 lpm. Elderly Chinese have PEFRs similar to those recorded in the Indian elderly population (51). These data suggest that PEFR is not greatly affected by ethnicity as has been thought hitherto.

Clinico-physiological applications: PEFR measurement may be carried out in the out patient department, as also at the bed side of the patient. Patients of asthma can be taught to use the peak flow meter to measure their own PEFR in order to monitor clinical status, as also their response to bronchodilator treatment. Usually, the patient is asked to record PEFR four times during the day and maintain a record for the treating physician to peruse. Large population surveys may be easily conducted using the peak flow meter. Directions for performing the PEFR manouevre is more easily understood by the subject/patient concerned as compared with the directions for performing the forced expiratory one. Also, the effort is less tiring as it is not required to be continued to residual volume. PEFR does not detect small airways obstruction. Nevertheless, it is a very useful diagnostic and prognostic variable obtained during spirometry.

Conclusions :

PEFR forms a part of routine spirometry. It may be done independently at the bed side, or in the field using a peak flow meter. The parameter is effort dependent, and the forced expiration is not required to be extended to residual volume when it is to be measured using the portable instrument. A set of regression equations for use for the Indian population has been derived.

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