Growth and other factors affecting peak expiratory flow rate

J W K CARSON,* H HOEY,*† AND M R H TAYLOR*†

*National Children's Hospital and †Department of Paediatrics, Trinity College, Dublin

SUMMARY By means of a simple questionnaire and measurements of height, weight, and peak expiratory flow rates 3061 children from city and rural populations were studied. Children with asthma or other respiratory diseases had lower peak expiratory flow rates, and younger children living in rural areas had higher rates. In 2828 healthy children the peak expiratory flow rate increased with age, height, and weight. There was an increase in the slope of this line for both age and height—at 12 years and 145 cm in girls, and at 14 years and 155 cm in boys. This continued for two to three years and 15 cm, respectively, before it declined. Previous surveys have obscured this change associated with height by reporting small numbers and using linear regression analysis. This type of analysis can underestimate the mean peak expiratory flow rate of small children by half to one standard deviation. A centile graph against age is recommended to describe normal values and their differences.

The Wright peak flow meter¹ is a practical and common way of measuring peak expiratory flow rate. It is easy to use, even for 3 to 5 year old children.² Lunn measured peak expiratory flow rate (PEFR) in over 3000 children,³ but his study was limited to city children aged 6 to 11 years; unhealthy children were not excluded and local air pollution was high.⁴ Other studies in normal children have been small and largely confined to city populations.⁵⁻⁹ We report the results of a study comprising over 3000 children aged 4 to 18 years drawn from both city and rural populations.

Subjects and methods

Children at school in the city of Dublin (population about 800 000), and smaller centres (population 5000-15 000) within 60 miles of Dublin, were surveyed with their parents' consent. A questionnaire was distributed to the parents enquiring about chronic illnesses (table 1). Height was assessed with a portable stadiometer by the same investigator throughout the study. Weight in underclothes was measured with an electronic balance. PEFR was measured with a Wright flow meter. Four meters were used and were calibrated by one of the authors against the manufacturer's submaster meter which is used to calibrate all new meters before issue. After the method had been shown to a group of five

children, each child had two or three practice blows, before three test blows done standing up with the neck held vertically and the tube of the meter held horizontally. The highest value reached was taken as the PEFR for that child. Social class was assessed according to the Registrar General's classification.¹⁰

Results

A total of 3061 children, 1528 boys and 1533 girls aged 4-19 years, were included in the analysis. Heights were not available for 79 children due to a fault in the stadiometer, and 233 children were excluded from the analysis of healthy children because of a chronic illness (assessed by the questionnaire), or an upper respiratory tract infection at the

Table 1 Questionnaire completed by parents

Does your child have:	Please tick:	
	Yes	No
1 Asthma	( )	( )
2 Chronic chest infection	( )	( )
3 Coeliac disease (on gluten free diet)	( )	( )
4 Chronic kidney disease	( )	( )
5 Other long term illness requiring regular hospital attendance:	( )	( )
Please name illness		

time of study. Eighty seven boys and 49 girls had asthma (4.4% of the total) (table 2), and 63 (35 boys and 28 girls) had no asthma but either chronic chest infections, atopic symptoms, or an upper respiratory tract infection at the time of the study; 34 (11 boys and 23 girls) had other non-respiratory chronic illnesses. There was no predisposition to ill health in any social class. Asthma was commoner in the 1550 city children (5.1%) than in the 1511 rural children (3.8%) but this difference was not significant.

Children with asthma had a mean PEFR 18.4 l/minute lower than the healthy children ($p<0.001$). Those with other respiratory diseases had a mean PEFR 37.3 l/minute lower than the healthy children ($p<0.001$). Overall, rural children had a significantly higher mean PEFR (+3.8 l/minute) than those living in the city ($p=0.032$). Similar

analysis for children under 12 years, however, showed a greater difference (mean +15.0 l/minute for rural children), but in those over 12 years old rural children had a lower PEFR (mean -8.0 l/minute) than those living in the city.

Multilinear regression analysis of PEFR against the following independent variables was done: height, age and weight, rural dwelling, social class, asthma, other respiratory disease, and other non-respiratory chronic disease (table 3). PEFR was not significantly associated with social class (whether taken as individual social classes or divided into two groups, manual and non-manual) or to non-respiratory chronic disease. Height, weight, age, and sex had a significant effect on PEFR ($p<0.001$). Linear regression analysis on the groups studied are shown in table 4.

There were 2828 healthy children, 1395 boys and 1433 girls, and the distribution of children by age is shown in table 5. The values for mean, standard deviation, and centiles of PEFR in age, height and weight groups are shown in tables 5, 6, and 7. Among girls there was a significant increase in the slope of the PEFR/age line at 12 years, which continued for two years (fig 1). A similar increase was seen in the slope of the PEFR/height line starting at 145 cm and continuing for 15 cm (fig 2). In both cases the change in slope was significant ($p<0.0001$). There was little increase in PEFR after this among girls. Among boys this change occurred at 14 years and at 155 cm, and continued for similar periods (fig 1 and 2). There was continued increase in PEFR among boys up to 19 years of age.

When the healthy rural children were compared with city children of the same height (table 8) the boys had higher PEFRs up to a height of 145 cm, and the girls from rural areas had higher PEFRs up to a height of 165 cm. In the group from the rural areas, the smaller girls had similar or higher PEFRs to the boys up to a height of 165 cm. When a similar comparison was made grouping the children by age

Table 2 Distribution by age and height of 135 asthmatic and 2847 non-asthmatic children

	Asthmatic	Non-asthmatic
Age (years):		
4-5	0	20
5-6	3	193
6-7	7	194
7-8	7	218
8-9	18	237
9-10	13	194
10-11	10	181
11-12	15	223
12-13	8	168
13-14	11	216
14-15	12	227
15-16	7	199
16-17	7	196
17-18	7	207
18-19	10	174
Height (cm):		
90-95	0	1
95-100	0	3
100-105	0	42
105-110	3	86
110-115	2	151
115-120	6	173
120-125	10	206
125-130	10	215
130-135	19	214
135-140	8	183
140-145	11	149
145-150	13	147
150-155	15	192
155-160	5	244
160-165	4	254
165-170	15	219
170-175	3	164
175-180	7	127
>180	4	77

Values are greater than lower limits and less than or equal to upper limits for each group.

Table 3 Multilinear regression analysis of 2982 children with accurate details on all variables

Variable	Regression coefficient	p Value (two tailed)
Intercept	-143.8	<0.001
Height	+1.91	<0.001
Weight	+2.24	<0.001
Age	+11.01	<0.001
Male sex	+20.6	<0.001
Asthma	-18.4	<0.001
Other respiratory disease	-37.3	<0.001
From rural area	+3.81	0.032

Table 4 Linear regression analysis of PEFR against height

	<i>a</i>	<i>b</i>	No of children	Correlation coefficient	Standard error of the estimate
<i>Healthy*</i>					
All					
{Boys	5.5985	-439.78	1395	0.9151	56.75
{Girls	5.1903	-390.58	1357	0.9053	47.24
Country					
{Boys	5.2416	-388.85	706	0.9086	55.68
{Girls	4.9363	-343.42	641	0.9072	44.83
City					
{Boys	5.9674	-493.88	689	0.9230	56.65
{Girls	5.5611	-454.38	716	0.9165	46.11
<i>Healthy and unhealthy*</i>					
City					
{Boys	5.9419	-492.55	771	0.9193	57.67
{Girls	5.5551	-454.48	779	0.9145	46.74
<i>Healthy boys and girls together†</i>					
City	91.3	65.858	1405	0.9213	52.32
<i>All healthy‡</i>					
{Boys	0.006760	1.5585	1395	0.9213	0.06564
{Girls	0.007225	1.4883	1357	0.8985	0.06845

*PEFR=a×(height in cm)+b; †PEFR=a×(height in metres)³+b; ‡log PEFR=a×height+b.

Table 5 Peak expiratory flow rates by age in centiles for 2828 healthy children

Age (years)	Sex	No of children	Mean (SD) peak expiratory flow rate for each group	Peak expiratory flow rate at:				
				97th centile	90th centile	50th centile	10th centile	3rd centile
4-5	M	8	207 (58)	290	290	180	125	125
	F	12	162 (52)	280	215	155	110	105
5-6	M	91	195 (41)	275	250	195	140	130
	F	88	180 (35)	260	225	180	135	125
6-7	M	97	217 (39)	290	270	215	165	145
	F	91	198 (38)	270	250	195	150	115
7-8	M	102	242 (43)	320	305	240	190	170
	F	109	231 (37)	295	280	230	185	155
8-9	M	112	276 (45)	350	330	280	210	195
	F	119	258 (39)	350	320	250	215	200
9-10	M	90	306 (49)	390	375	300	245	205
	F	98	290 (39)	345	340	285	235	215
10-11	M	79	325 (45)	405	380	335	250	235
	F	95	305 (42)	375	355	300	245	235
11-12	M	100	353 (48)	425	405	355	290	245
	F	115	333 (47)	410	385	335	265	250
12-13	M	88	377 (47)	485	430	375	310	300
	F	103	369 (49)	450	435	370	305	275
13-14	M	116	404 (60)	525	495	405	330	300
	F	109	421 (48)	505	490	425	355	340
14-15	M	100	450 (64)	570	535	445	365	335
	F	135	440 (46)	520	500	440	385	355
15-16	M	107	499 (72)	615	595	505	400	340
	F	93	448 (51)	545	510	450	385	350
16-17	M	101	552 (63)	650	620	565	475	400
	F	97	460 (45)	550	525	455	400	390
17-18	M	109	569 (66)	695	640	570	480	430
	F	94	468 (49)	550	525	475	405	370
18-19	M	95	602 (64)	720	690	605	515	485
	F	75	478 (47)	555	535	485	420	380

Figures given as unsmoothed values. Values are greater than lower limit and less than or equal to upper limit for each group.

Table 6 Peak expiratory flow rates by height for 2752 healthy children. Figures are shown for boys/girls

Height (cm)	No of children	Mean (SD) peak expiratory flow rate for each group	Mean peak expiratory flow rate at:		
			90th centile	50th centile	10th centile
90-95	1/0	131/0 (0/0)	0/0	0/0	0/0
95-100	1/2	170/188 (0/54)	0/0	0/0	0/0
100-105	18/22	168/161 (30/35)	210/190	165/175	125/115
105-110	41/41	193/174 (37/44)	240/215	190/170	145/125
110-115	65/79	206/194 (40/37)	255/240	205/195	160/155
115-120	79/86	222/214 (44/46)	260/260	210/210	185/160
120-125	95/106	250/244 (42/41)	305/290	250/240	195/195
125-130	90/116	269/273 (43/43)	320/335	270/270	210/220
130-135	96/112	297/299 (49/51)	355/360	305/290	240/235
135-140	80/94	326/308 (41/44)	385/360	330/305	265/250
140-145	77/67	344/332 (41/52)	390/395	350/335	280/265
145-150	87/57	365/370 (38/52)	415/440	365/370	310/305
150-155	89/98	382/409 (53/48)	455/475	380/410	315/345
155-160	71/167	412/443 (54/46)	485/510	415/445	345/385
160-165	75/171	469/457 (72/51)	575/520	460/460	395/390
165-170	111/99	514/470 (77/48)	605/525	515/470	420/405
170-175	129/30	545/484 (69/47)	635/525	545/490	455/420
175-180	118/8	568/493 (69/53)	660/0	570/0	485/0
>180	72/2	584/474 (69/6)	675/0	585/0	510/0

Figures given as unsmoothed values.

Table 7 Peak expiratory flow rates, by weight for 2828 healthy children. Figures are shown for boys/girls

Weight (kg)	No of children	Mean (SD) peak expiratory flow rate for each group	Mean peak expiratory flow rate at:		
			90th centile	50th centile	10th centile
<15	2/2	179/163 (67/19)	0/0	0/0	0/0
15-20	103/108	191/185 (38/47)	250/235	190/180	145/130
20-25	197/221	237/225 (43/47)	290/280	235/225	180/165
25-30	183/202	287/274 (52/46)	355/335	290/270	220/215
30-35	143/135	328/318 (50/50)	390/385	335/310	255/255
35-40	121/113	370/347 (48/49)	430/400	365/355	310/275
40-45	98/113	391/400 (51/53)	455/470	385/400	335/330
45-50	80/148	430/431 (69/53)	515/505	430/430	340/365
50-55	97/159	480/449 (70/48)	575/510	485/445	400/390
55-60	106/114	526/465 (70/52)	605/525	535/470	425/405
60-65	107/70	551/471 (72/48)	630/520	560/475	445/410
65-70	78/31	592/471 (63/38)	685/510	590/470	520/425
70-75	46/13	589/486 (65/52)	680/0	585/0	505/0
75-80	18/3	553/480 (73/47)	645/0	540/0	440/0
80-85	9/0	610/0 (71/0)	0/0	0/0	0/0
>85	7/1	610/464 (71/0)	0/0	0/0	0/0

Figures given as unsmoothed values.

instead of height, however, there was little difference between the rural and city children.

Discussion

Our results confirm that children with respiratory disease have lower values of PEFR than normal children. Those children with respiratory disease but no history of asthma had a particularly low mean

PEFR, which suggests that some of these children had asthma and were not getting appropriate treatment.¹¹

Although our study showed a significantly higher mean PEFR in the rural children, this difference was greater among the children under 12 years. The inclusion of older rural children as boarders in the city secondary schools may have increased the level of PEFR in these older age groups, but we have no

Fig 1 Peak expiratory flow rate and age, 10th and 50th centile lines (unsmoothed values).

Fig 2 Peak expiratory flow rate and height, 10th and 50th centile lines (unsmoothed values).

record of the numbers of rural boarders in city schools. Air pollution may have been another factor.

The median smoke levels in Dublin at the time of the study were between 25–80 $\mu\text{g}/\text{m}^3$.¹² In Sheffield (where Lunn's study was carried out) the mean daily figures in the winter 1965–6 were 97–301 $\mu\text{g}/\text{m}^3$.⁴ The lower air pollution and the inclusion of rural children boarding in city schools in the present study may account for the higher PEFR values in the city children when compared with the results from Sheffield and with the other studies of city children in the 1960s (table 9). In addition the Sheffield study did not exclude unhealthy children.

When the results of the study by Godfrey *et al*⁷ are compared with our results for city children analysed in the same way (linear regression) the results are similar in the younger children (table 9). There is good correlation for the girls throughout, and for boys below 135 cm in height. Above this, the difference increased from 21 to 45 l/minute. Not all the differences can be satisfactorily explained. Factors such as smoking by the children or their parents were not assessed in either study. Genetic differences as shown by measurement of lung volumes of children of different races¹³ may also be a factor.

In this study the centile method of analysis gives a much higher mean value for PEFR in small and tall children than linear regression. Linear regression might give a poor estimate of central tendency at the extremes of the data and would also conceal the peripubertal acceleration. The linear regression method underestimates the PEFR in small children by 30 l/minute for boys and 19 l/minute for girls. These differences are close to one standard deviation for boys and half a standard deviation for girls. There are similar but smaller differences among taller children, where the regression analysis underestimates the value for boys and overestimates the value for girls (table 9). Smoothing for centile lines also has the disadvantage of concealing the peripubertal acceleration.

In other smaller studies the results have been presented as a linear correlation with height^{5–8} or as an exponential of height.^{8,9} The PEFR/height graphs of Nairn *et al*⁵ showed a similar pattern to our results, but they used a linear regression analysis relating PEFR to height as have many studies of forced expiratory volume in one second,^{5–7} which have shown a similar pattern in their graphs.^{14,15}

This is the largest study of PEFR in healthy children so far reported. The results show that changes take place in PEFR about the time of puberty but are not in phase with other growth changes. These changes have been obscured in

Table 8 Mean peak expiratory flow rates of 2752 healthy children by height and where they lived. Figures are shown for boys/girls

Height (cm)	Children living in city (n=1409)		Children living in rural areas (n=1343)		Difference between mean peak expiratory flow rate in rural and city children
	No of children	Mean peak expiratory flow rate	No of children	Mean peak expiratory flow rate	
90-95	1/0	131/0	0/0	0/0	0/0
95-100	1/2	170/188	0/0	0/0	0/0
100-105	5/8	155/135	13/14	173/175	18/40
105-110	18/18	173/159	23/23	208/186	35/27
110-115	30/40	197/180	35/39	213/209	-2/41
115-120	39/41	223/192	40/45	221/233	22/34
120-125	37/50	236/226	58/56	258/260	11/29
125-130	42/47	263/256	48/69	274/285	11/29
130-135	45/50	289/276	51/62	305/316	16/40
135-140	38/48	323/292	42/46	328/325	5/33
140-145	41/44	342/322	36/23	346/350	4/28
145-150	42/33	365/357	45/24	365/387	0/30
150-155	43/64	386/405	46/34	378/417	-8/12
155-160	35/98	421/438	36/69	404/449	-17/11
160-165	46/89	475/454	29/82	460/459	-15/5
165-170	55/64	517/470	56/35	511/470	-6/0
170-175	63/17	555/482	66/13	535/487	-20/-5
175-180	64/3	581/485	54/5	553/498	-28/13
>180	46/2	593/474	26/0	568/0	-25/0

Table 9 Expected values of PEFR for given height according to different sources and methods of analysis (boys/girls)

	<i>Total No</i>	<i>Height (cm)</i>				
		<i>105</i>	<i>115</i>	<i>135</i>	<i>155</i>	<i>170</i>
This study						
All healthy						
Centile chart	2752	178/173	208/203	318/298	400/428	530/480
Linear regression	2752	148/154	204/206	316/310	428/414	512/492
Healthy in rural areas*	1347	162/175	214/224	319/323	424/422	502/496
Healthy in cities*						
This study	1405	133/130	192/185	312/296	431/408	521/491
Godfrey <i>et al</i> ⁷	382	132/132	185/185	291/290	397/396	476/475
Murray and Cook ⁸	220	120/144	178/191	290/284	404/377	490/447
Weng and Levison ⁶	139	139	185	283	381	454
(boys and girls combined)						
Healthy and unhealthy in cities*						
This study	1347	131/128	191/184	310/295	428/407	518/490
Lunn ³	3556	—	175/167	254/251	—	—
Healthy in cities† (boys/girls combined)						
This study	1405	172	205	290	406	514
Bjore <i>et al</i> ⁹	214	—	206	274	365	451

*Linear regression; †linear regression based on height in m³.

previous studies by the types of analysis used. The timing of the increase in the slope of the PEFR against age, height, or weight lines may depend on the timing of puberty, and this varies in different countries. The mean (SD) age of menarche for Irish girls is 13.5 (1.3) years.¹⁶ In the girls in this study the spurt in PEFR overlaps the menarche, and so follows the height spurt that normally precedes the menarche.

In view of these findings we suggest that a 'centile chart' approach to normal values of PEFR is a more appropriate representation of normal values than the conventional straight line graph usually used for children. A centile chart is the accepted method of presenting normal values for height and weight, and it seems sensible to apply it to pulmonary function as well. Charts of PEFR for age (figs 3 and 4 based on table 5) rather than height are probably more

Fig 3 Peak expiratory flow rate and age; centile chart for boys (smoothed values).

Fig 4 Peak expiratory flow rate and age; centile chart for girls (smoothed values).

convenient for rapid reference in an accident and emergency department or a busy general practice when accurate heights are not readily available.

We thank the children, their parents, and their teachers whose cooperation was essential for the completion of this study, as well as our many helpers in the National Children's Hospital and Trinity College, Dublin.

References

- Wright BM, McKerrow CB. Maximum forced expiratory flow rate as a measure of ventilatory capacity. *Br Med J* 1959;ii: 1041-7.
- Milner AD, Ingram D. Peak expiratory flow rates in children under 5 years of age. *Arch Dis Child* 1970;45:780-2.
- Lunn JE. Respiratory measurements of 3,556 Sheffield schoolchildren. *British Journal of Preventive and Social Medicine* 1965;19:115-22.
- Lunn JE, Knowelden J, Handyside AJ. Patterns of respiratory illness in Sheffield infant schoolchildren. *British Journal of Preventive and Social Medicine* 1967;21:7-16.
- Nairn JR, Bennett AJ, Andrew JD, MacArthur P. A study of respiratory function in normal school children. *Arch Dis Child* 1962;36:253-8.
- Weng T-R, Levison H. Standards of pulmonary function in children. *Am Rev Respir Dis* 1969;99:879-94.
- Godfrey S, Kamburoff PL, Nairn JR. Spirometry, lung volumes and airway resistance in normal children aged 5 to 18 years. *Br J Dis Chest* 1970;64:15-24.
- Murray AB, Cook CD. Measurement of peak expiratory flow rates in 220 normal children from 4-5 to 18-5 years of age. *J Pediatr* 1963;62:186-9.
- Bjore J, Dalen G, Kjellman B. Peak expiratory flow rate. Reference values for Swedish children. *Acta Paediatr Scand* 1979;68:605-7.
- Registrar General. *Classification of occupations 1970*. London: HMSO, 1971.
- Speight ANP, Lee DA, Hey EN. Underdiagnosis and undertreatment of asthma in childhood. *Br Med J* 1983;286:1253-6.
- Riley P. *Environment pollution report 1983/4*. Dublin: Health inspectorate, atmospheric pollution and noise control unit, Dublin Corporation, 1984.
- Binder RE, Mitchell CA, Schoenberg JB, Bouhuys A. Lung function among black and white children. *Am Rev Respir Dis* 1976;114:955-9.
- Strang LB. The ventilatory capacity of normal children. *Thorax* 1959;14:305-10.
- Dickman ML, Schmidt CD, Gardner RM. Spirometric standards for normal children and adolescents (ages 5 years through 18 years). *Am Rev Respir Dis* 1971;104:680-7.
- Hoey H, Cox L, Tanner J. The age of menarche in Irish girls. *Ir Med J* 1986;79:283-5.

Correspondence to Dr JWK Carson, National Children's Hospital, Harcourt Street, Dublin 2, Ireland.

Accepted 14 June 1988