ADAPTATION OF THE WRIGHT PEAK FLOW METER TO MEASURE INSPIRATORY FLOW

BY

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A new portable instrument for measuring maximum forced expiratory flow in litres per minute was described by Wright and McKerrow (1959). This instrument, now known as the Wright peak flow meter, has become popular because of its ease of use, portability, and mechanical reliability. As an expression of ventilatory capacity the peak flow has been challenged because it records flow only over the very short time interval of 10 millisecs. Nevertheless it has been shown to parallel other measurements of ventilatory function and to discriminate between grades of disability and symptoms in several studies (Lockhart, Smith, Mair, and Wilson, 1960; Prime, 1960; Fletcher and Tinker, 1961; College of General Practitioners, 1961; Read and Selby, 1961).

Expiratory flow can be reduced by many different mechanisms, such as narrowing of the bronchial lumen by tumour, mucosal swelling, secretions, smooth-muscle spasm, or inward collapse of the bronchial walls. The bronchial collapse mechanism occurs in emphysema on expiration and is explained by lack of support for the walls and by the fall in intrabronchial pressure normally derived from the elastic recoil of the lungs. Inspiration remains relatively unimpaired, and for this reason a comparison of the expiratory and inspiratory spirograms is useful and has been recommended (Ciba Symposium, 1959; W.H.O., 1961). Using a light spirometer and rapid kymograph McNeill, Malcolm, and Brown (1959) compared the maximum expiratory and inspiratory flow by measuring the time taken to expire and inspire a litre of gas between 200 and 1,200 ml. and converting this to litres per minute. This method has been described by Comroe, Forster, Dubois, Briscoe, and Carlsen (1955), with the claim that it gave values comparable to those obtained by an electrical pneumotachograph. In an attempt to obtain similar information rapidly and easily and without the necessity for spirometer or kymograph, we have adapted the Wright peak flow meter to measure inspiratory flow.

Description and Characteristics of the Meter

A gasket has been applied around the rim of the exhaust portholes of the meter and a "perspex" back with exit pipe has been screwed on to make an airtight joint (Fig. 1). The back clears the meter by 2 cm. The exit pipe is 4.5 cm. long and has the same diameter as the inlet pipe, so that the plastic mouthpiece can be inserted at either end. The subject applies his mouth to the exit side and expires gently but fully. He then reverses suddenly and inspires at maximum speed. This manœuvre is more difficult to learn than forced expiration, but it can usually be mastered after two or three trials.

The addition of the back portion raised the possibility of increased resistance to expiration. To test this, the peak expiratory flow (P.E.F.) of 12 subjects was measured with and without the back portion and there was no significant difference in the results.

The meter was also calibrated with the back both on and off against known steady flow rates. These were produced by pumping air into a vessel at constant pressure and allowing it to flow through a calibrated pipe orifice meter. As can be seen (Fig. 2), there was a very slight but consistent reduction in peak flow values of about 2% or less with the back on. By using a fan blower in reverse air was sucked through the meter, and although it was possible to do this only over a much narrower range it can be seen that the results fall on the calibration lines for forward flow.

Our conclusions were that the addition of the back portion did not add significantly to the resistance of the meter and that flow rates similar to those obtained by forward flow are obtained if suction is applied to the exhaust side.

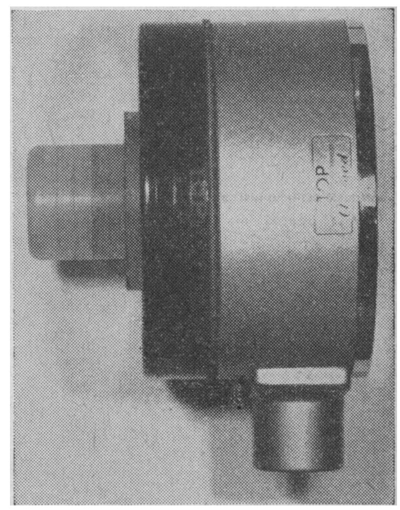

FIG. 1.—Peak flow meter with perspex back fitted for recording inspiratory flow.

Hygiene

With this adaptation the danger of inhaling pathogenic bacteria arose, and indeed we were questioned about this by a few of our more fastidious subjects. To test the danger, three subjects blew through the plastic mouthpiece, first directly and then through the meter on to a blood-agar plate. To our surprise hardly any bacteria were grown and no pathogens were isolated. Similar results were obtained by

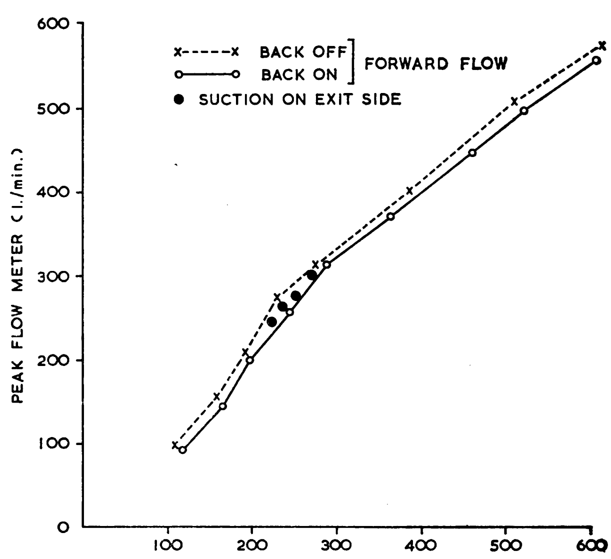

FIG. 2.—Peak flow meter with and without modification, calibrated against steady flow.

expelling room air forcibly from a rubber bag. The exhaust side of the meter was also swabbed before and after 25 forced expirations and no organisms were grown.

We do not claim that there is no risk of infection, but we believe it is small and does not raise a serious objection to the adaptation of the meter. Sterilization by heat would not be suitable because of the materials used, and it would also take too long between cases. Perhaps the most simple solution would be to keep a meter for inspiratory use only.

Results in Normals

The normals (52 males, 47 females) came from different departments in the hospital but also included a few visitors. They did not include any who had a history of recent or chronic pulmonary disease. For the tests two trials were allowed and then the next three readings were recorded. The mean values were used and the results for P.E.F. and P.I.F. are shown in Tables I and II. For both males and females and in each age-group inspiratory flow is less than expiratory, and the P.E.F./P.I.F. ratio varies from 1.14 to 1.36. In eight individuals, however, P.I.F. actually exceeded P.E.F. although the P.E.F./P.I.F. ratio never fell below 0.9.

Maximum expiratory and inspiratory flow was also measured by the spirometric method previously referred to and the correlation with peak flow is shown (Figs. 3 and 4).

Coefficients of variation between trials in the same persons for the spirometric method have been reported previously as 7.4% for expiration and 8.8% for inspiration (McNeill *et al.*, 1959). Using the peak flow meter, we have found the coefficient of variation of triplicate readings to be 4.5% for expiration, which is similar to that reported by Lockhart *et al.* (1960), Shephard (1962), and Fairbairn, Fletcher, Tinker, and Wood (1962). For P.I.F. the coefficient of variation is 9.4%, which is twice that for expiration and reflects the greater difficulty of instructing subjects in the technique of maximum forced inspiration.

TABLE I.—*Peak Expiratory Flow (litres/min.) in Normals*

	15–24 Years	25–34 Years	35–44 Years	45–54 Years	55–65 Years
Males (52)	601 (7)	575 (15)	530 (9)	523 (11)	465 (10)
Females (47)	431 (8)	425 (13)	388 (9)	388 (16)	300 (1)

Males.—Mean age, 40 years. Mean P.E.F., 539 l./min. Correlation with age: $r = -0.59$ ($P < 0.001$).
Females.—Mean age, 37 years. Mean P.E.F., 404 l./min. Correlation with age: $r = -0.42$ ($P < 0.01$).

TABLE II.—*Peak Inspiratory Flow (litres/min.) in Normals*

	15–24 Years	25–34 Years	35–44 Years	45–54 Years	55–65 Years
Males (52)	473 (7)	474 (15)	456 (9)	448 (11)	408 (10)
Females (47)	342 (8)	322 (13)	305 (9)	306 (16)	220 (1)

Males.—Mean age, 40 years. Mean P.I.F., 453 l./min. Correlation with age: $r = -0.27$ ($P < 0.05$).
Females.—Mean age, 37 years. Mean P.I.F., 314 l./min. Correlation with age: $r = -0.33$ ($P < 0.05$).

Results in Patients

To demonstrate the clinical use of the adapted peak flow meter illustrative cases are listed in Table III. In the emphysematous patients it is obvious that the P.I.F. exceeds the P.E.F. and the P.E.F./P.I.F. ratio falls to 0.40 to 0.59. In the other conditions shown the usual relationship exists and the P.E.F./P.I.F. ratio is greater than 1. This may hold even when there is considerable disability and even when the resistance of the airways is greatly increased as in severe asthma uncomplicated by emphysema.

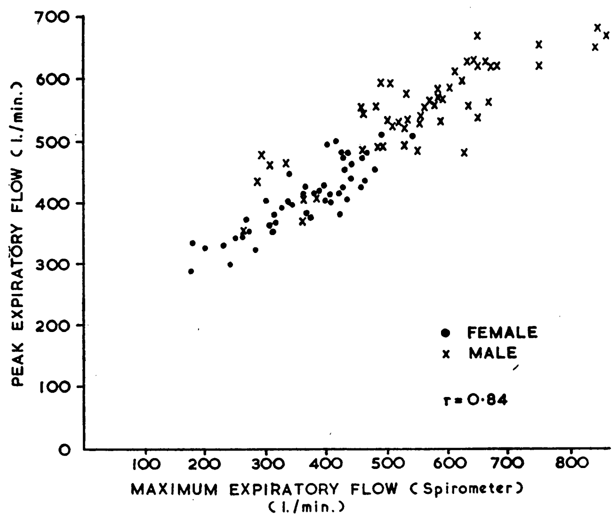

FIG. 3.—Correlation of spirometric and peak flow meter readings of expiratory flow in normal subjects.

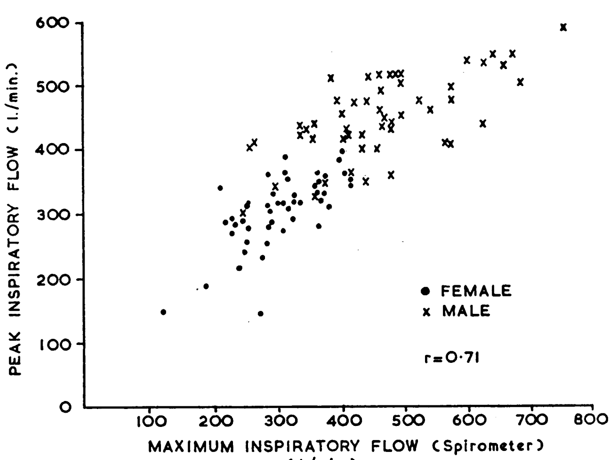

FIG. 4.—Correlation of spirometric and peak flow meter readings of inspiratory flow in normal subjects.

TABLE III.—*Peak Expiratory and Inspiratory Flow and Other Tests of Pulmonary Function in Patients*

Sex and Age	Diagnosis	Vital Capacity (V.C., ml.)	Residual Volume (R.V., ml.)	$\frac{R.V.}{T.L.C.}$%	Arterial P_{CO_2} mm. Hg	F.E.V.$_1$ ml.	$\frac{F.E.V._1}{V.C.}$%	P.E.F. l./min.	P.I.F. l./min.	$\frac{P.E.F.}{P.I.F.}$
M 57	Emphysema	2,590	4,922	66	52	514	20	70	175	0·40
M 49	,,	4,340	6,540	60	38	943	22	185	315	0·59
M 61	,,	3,280	3,250	50	43	780	24	220	395	0·56
M 63	,,	2,300	7,360	76	53	614	27	115	215	0·54
F 37	Severe asthma. Rheumatic heart disease	2,240	3,688	62	—	1,000	45	85	65	1·31
F 48	Status asthmaticus	—	—	—	—	—	—	155	110	1·41
F 60	Laryngeal palsy (post-thyroidectomy)	3,910	2,240	36	43	2,343	60	235	60	3·92
F 67	Pulmonary sarcoidosis	2,515	1,326	35	40	2,320	93	305	175	1.74
M 15	Kyphoscoliosis	1,612	1,233	43	45	1,612	100	260	135	1·93

Discussion

Our normal values for P.E.F. are similar to those quoted by others (Higgins, 1957 ; Tinker, 1961 ; College of General Practitioners, 1961 ; Read and Selby, 1961 ; Shephard, 1962) but are closest to those reported from the same city by Lockhart *et al.* (1960). We are not aware of published values for inspiratory flow measured by the peak flow meter, but we have found a good correlation with maximum inspiratory flow measured by the spirometric method (Fig. 4). The technique of maximum forced inspiration is undoubtedly more difficult to master. Nevertheless it is nearly always possible, and since we are interested in the alteration of the normal P.E.F./P.I.F. ratio rather than in absolute values, the coefficient of variation is of less importance.

We do not wish to imply that all patients with emphysema can be picked out with ease by the P.E.F./P.I.F. ratio. A patient with emphysema may have a surprisingly good P.E.F. as compared with other tests of ventilatory function. The explanation may be that the sudden and abrupt collapse of the bronchial walls displaces sufficient air to give a spuriously high reading on the meter. This flow, however, is not maintained long enough to be functionally useful and the patient may be seriously disabled. Nevertheless, we have usually found that when the forced expiratory and inspiratory spirograms show a selective impairment of expiration the peak flow meter shows a fall in the normal P.E.F./P.I.F. ratio.

Several reasons for increased airways resistance may be present in the same patient. Bronchial secretions or smooth-muscle spasm also impair inspiratory flow, and if present may mask the effect of "pure" emphysema. The significance of the fall in P.E.F./P.I.F. ratio is therefore more in its presence than in its absence, but when the fall is present and marked there is strong presumptive evidence of mechanical change in the lungs due to emphysema. In other less usual cases, such as the patient with laryngeal obstruction, useful information may be obtained by measuring the inspiratory flow. This patient was severely disabled, and, although the laryngeal obstruction was recognized, underlying emphysema was suspected. In fact, the severe and selective impairment of inspiration present was incompatible with the latter diagnosis. We have found in these and other cases that this simple modification of the peak flow meter has provided useful additional information.

Summary

An adaptation of the Wright peak flow meter is described which enables peak inspiratory flow to be measured. The original mechanical characteristics of the meter have not been altered by this.

The peak expiratory and peak inspiratory flow of 52 normal males and 47 normal females are presented. Both measurements show a fall with increasing age.

Normally, peak expiratory flow exceeds inspiratory. In patients suffering from emphysema a reversal of this ratio is commonly seen. This is interpreted as evidence of the bronchial collapse mechanism. The ability to measure peak inspiratory flow is also of value in other conditions.

We are very grateful for assistance from members of various departments of Queen's College, Dundee. Mr. Alex. Soutar, of the Department of Pharmacology and Therapeutics, skilfully adapted a Wright peak flow meter purchased from Airmed Ltd., London; Mr. W. McNicoll, of the Department of Civil and Mechanical Engineering, calibrated it against steady flow; and Dr. D. M. Green carried out the bacteriological studies. We are also grateful to members of the Department of Social Medicine for the statistical analysis.

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PARATHYROID INSUFFICIENCY AFTER THYROIDECTOMY

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A proportion of patients who undergo thyroidectomy develop tetany owing to a fall in the serum calcium. Reduced parathyroid function is responsible for this fall, and in some cases one or more parathyroid glands may be found on the operation specimen (Murley and Peters, 1961). However, in most cases no parathyroid tissue has been removed, and impaired function is probably due to damage to the blood supply of the parathyroid glands (Halsted and Evans, 1907). Occasionally, in toxic cases, tetany occurs as a result of the "hungry bones" phenomenon (Dent and Harper, 1958). Tetany is usually short-lived, and with its disappearance it has sometimes been assumed that parathyroid function has returned to normal. That this is not necessarily true is well established, and there is no doubt that a severe degree of hypocalcaemia can exist in the absence of tetany. The effects of this are sometimes both subtle and serious, and persistent hypocalcaemia may result in cataract formation (Lachmann, 1941) or in psychotic illness, usually of a depressive nature. Moreover, a variety of less serious symptoms, such as headache, lethargy, and abdominal pain, have also been ascribed to hypocalcaemia by Davis *et al.* (1961).

The lowest post-operative serum-calcium level that can be regarded as normal has not been agreed. Wade (1960) thought that any patient with a serum-calcium level between 8 and 9 mg./100 ml. was in need of treatment, and those with a level below 7.5 mg./100 ml. were in need of urgent treatment. Wade found only two cases of permanent hypoparathyroidism in his own