

# Peak expiratory flow at altitude

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## Abstract

The mini Wright peak flow meter is a useful, portable instrument for field studies but being sensitive to air density will under-read at altitude. True peak expiratory flow will increase at altitude, however, because of the decreased air density, given that dynamic resistance is unchanged. The effect of simulated altitude on peak expiratory flow (PEF) was determined in six subjects with both the mini Wright meter and a volumetric spirometer (which is unaffected by air density). With increasing altitude PEF as measured by the spirometer increased linearly with decreasing pressure, so that at a barometric pressure of 380 mm Hg\* (half an atmosphere, corresponding to an altitude of 5455 m) there was a 20% increase over sea level values. The mini Wright flow meter gave readings 6% below sea level values for this altitude—that is, under-reading by 26%. Measurements of PEF made at altitude with the mini Wright meter should be corrected by adding 6.6% per 100 mm Hg drop in barometric pressure.

The mini Wright peak flow meter<sup>1</sup> is a small, cheap, easily portable instrument weighing 75 g. It therefore lends itself to field measurements of peak expiratory flow (PEF),<sup>2</sup> a reproducible index of ventilatory function. Using the standard Wright peak flow meter Singh *et al* found a reduction in PEF in 23 of 24 subjects who developed symptoms of mountain sickness.<sup>3</sup> Stockley and Green also showed a fall in PEF at altitude that was more pronounced in those who developed acute mountain sickness.<sup>4</sup>

With the decrease in air density at altitude, however, the peak flow meter will under-read.<sup>5,6</sup> The same decrease in air density, however, must result in an increase in the true PEF if dynamic airways resistance remains unchanged. When the peak flow meter is used at altitude these two effects would tend to cancel each other out.

To see if this is the case and to document the change with altitude in PEF as measured by the spirometer, we carried out a study at simulated altitude, using the peak flow meter and a spirometer to measure PEF and determine the maximum expiratory flow-volume curve.

## Methods

Six healthy men sat in a decompression chamber at the RAF Institute of Aviation Medicine, Farnborough. They breathed 40% oxygen when barometric pressure was 520 mm Hg or less. Oxygen masks were removed two minutes before they performed a respiratory test. The best of three PEF readings was recorded, a mini Wright peak flow meter being used (Airmed, Clement Clarke International). Three forced vital capacity (FVC) manoeuvres were recorded with a rolling seal spirometer (Spiroflow, P K Morgan, Chatham). The electronic output of the latter was interfaced with an Amstrad 1640 PC microcomputer to derive flow-volume loops for expiration and inspiration. These measurements were made at sea level at the beginning and end of the experiment and at three levels of decompression. The chamber was decompressed from sea level (760 mm Hg) to the equivalent of 5455 m (380 mm Hg) over six minutes. Thereafter pressures equivalent to altitudes of 4242 m (447 mm Hg) and 3030 m (520 mm Hg) were attained at 10 minute intervals before the return to sea level pressure. The total experimental time was about 90 minutes.

The relation of PEF to barometric pressure was modelled for each subject with the GLIM 3.77 software package,<sup>7</sup> pressure being used as the covariate to test the linearity of the relationship.

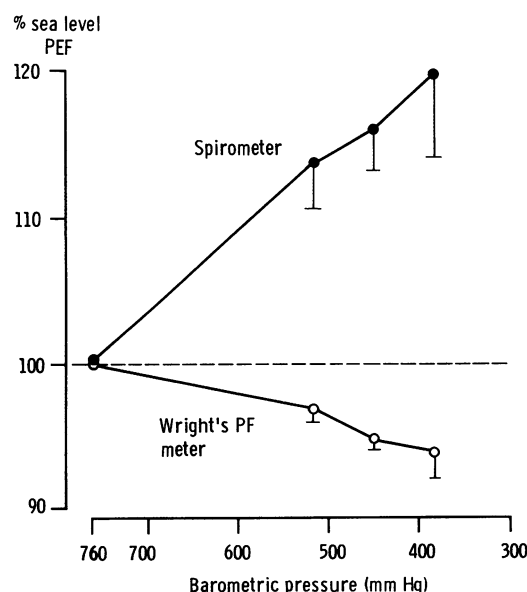


Figure 1 Peak expiratory flow (PEF) as percentage of sea level value for six subjects measured by spirometer (●) and by the mini Wright peak flow (PF) meter (○) at simulated altitude. Bar lines indicate 1 SEM.

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\*1 mm Hg  $\approx$  0.133 kPa.

Peak expiratory flow measurements (l/s) obtained from a spirometer and a mini Wright peak flow meter at sea level (SL) and three simulated altitudes

Subject No	760 (SL1*)	380 (5455)	447 (4242)	520 (3030)	760 (SL2*)	Mean SL
<b>SPIROMETER</b>						
1	8.46	10.57	9.71	9.54	9.27	8.86
2	8.21	11.71	10.23	10.77	8.78	8.50
3	8.74	9.23	11.15	10.23	9.41	9.07
4	7.51	10.78	9.63	10.54	10.28	8.89
5	10.32	13.13	11.86	11.28	10.04	10.18
6	9.96	10.90	11.67	10.60	10.00	9.98
Mean	8.87	11.05	10.71	10.50	9.63	9.25
SD	1.07	1.29	0.98	0.58	0.57	0.67
<b>MINI WRIGHT PEAK FLOW METER</b>						
1	8.50	8.33	8.17	8.33	8.50	8.50
2	9.00	9.00	8.83	8.67	9.17	9.08
3	10.00	9.17	9.50	9.67	10.00	10.00
4	10.50	9.33	10.17	11.17	11.67	11.08
5	10.17	9.50	9.50	9.67	10.00	10.08
6	9.83	9.33	9.17	9.50	9.67	9.75
Mean	9.66	9.11	9.22	9.50	9.83	9.75
SD	0.76	0.40	0.67	1.00	1.05	0.88

\*1 and 2 indicate before and after decompression.

## Results

No subject suffered side effects or noticed symptoms of altitude sickness.

The results are summarised in the table and figure 1. PEF at sea level pressure measured with the peak flow meter did not differ significantly from PEF measured with the spirometer, nor was there any significant difference between sea level values at the beginning and end of the study (table). Subject 4 had no previous experience of FVC manoeuvres and seemed to show a learning effect through the study. His first PEF (spirometer and meter) was probably below his true value.

The PEF measured by spirometer increased

with decreasing pressure to show a 20% increase at 380 mm Hg (5455 m). There was a small, steady fall in the PEF measured by the peak flow meter with increasing altitude. Both these changes of PEF with pressure were significant ( $p < 0.001$ ).

Modelling the results from both instruments showed that the relationship of PEF with barometric pressure was linear, the slope being negative for the spirometer and positive for the peak flow meter. The mean and SD of the slopes for change in PEF (l/s) per mm Hg pressure were:

Spirometer  $-0.0048$  (0.0008)

Peak flow meter  $+0.0016$  (0.0004).

The relation with pressure for individual subjects was linear (rather than, for instance, quadratic).

The mean maximum expiratory flow-volume curves for sea level and 5455 m (380 mm Hg) show that the increased flow at altitude continues down to 25% of vital capacity (fig 2). Maximum inspiratory flows were also increased at altitude. There was no significant change in FEV<sub>1</sub> or FVC.

## Discussion

The spirometer measured PEF rises progressively with decreasing barometric pressure when there is no change in dynamic airways resistance. (Being a volumetric instrument, the spirometer is unaffected by changes in air density.) At a pressure of half an atmosphere (380 mm Hg) PEF has increased by 20%. The flow at lung volumes down to 25% FVC was also found to be increased (fig 2). This is in line with the results of studies using helium-oxygen

Figure 2 Mean maximum expiratory flow-volume loops of six subjects at sea level and at simulated altitude (380 mm Hg pressure). Bar lines indicate 1 SEM.

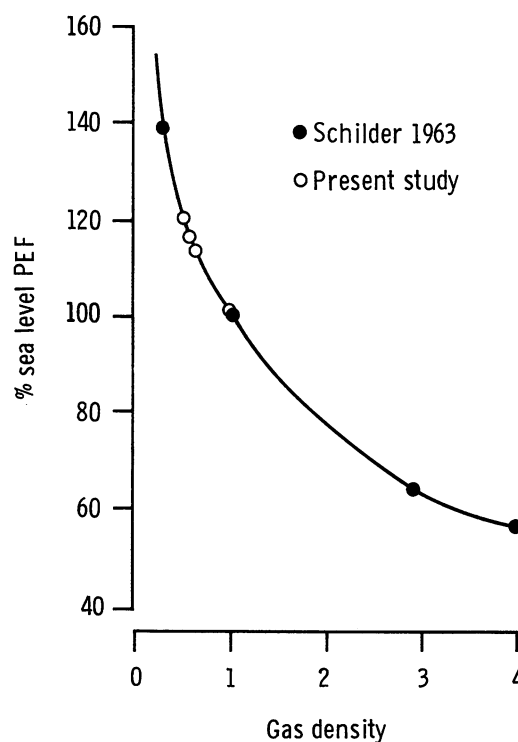
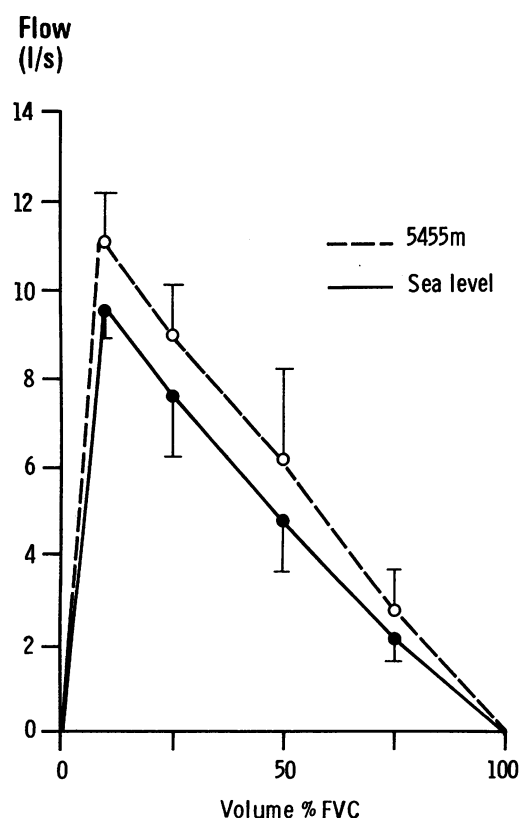


Figure 3 Effect of change of inspired gas density on peak expiratory flow (PEF), air at sea level being taken as unity: data from Schilder et al and the present study.

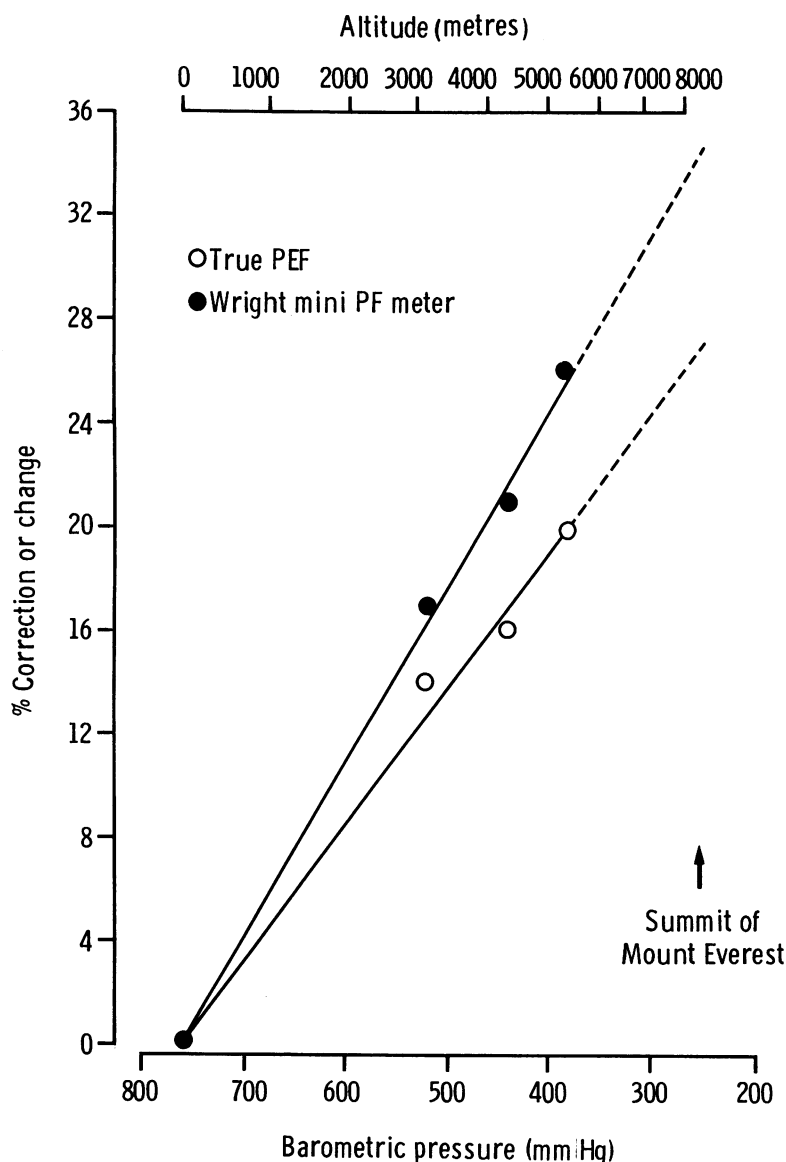


Figure 4 Effect of reduced barometric pressure or altitude on spirometer measured peak expiratory flow (PEF), as percentage change from sea level value, and the correction to be applied to PEF measured by a mini Wright peak flow meter to obtain true PEF (●). Note that the altitude scale is non-linear.

mixtures to change gas density, where the effect was seen down to about 10% in non-smokers and 20% in smokers.<sup>8</sup>

The mini Wright peak flow meter, which is sensitive to air density, under-reads by 26% at half atmospheric pressure (380 mm Hg, 5455 m) and gives readings for PEF 6% less than at sea level. This latter result is similar to the findings of Forster and Parker,<sup>5</sup> who, using a mini Wright peak flow meter, found a reduction in PEF of 6.8% in subjects taken rapidly to 4200 m.

The results of earlier studies showing a reduction in PEF at altitude may be confounded by the under-reading of the peak

flow meter that we found. The study by Singh *et al*<sup>2</sup> does show that as acute mountain sickness subsides PEF improves, suggesting that interstitial pulmonary oedema was also contributing to the reduced PEF.

The effect of gas density on PEF can be studied by inhalation of gas mixtures of varying density at sea level. Data derived from such a study<sup>9</sup> are plotted as percentage PEF change against gas density in figure 3. The relationship is curvilinear. The values obtained in the present study (also shown in fig 3) fall on this line, suggesting that changes in PEF at altitude are accounted for by changes in air density.

Our results for change in spirometer measured PEF with altitude and the correction to be applied to PEF measured with the peak flow meter to obtain a "true" PEF for any given altitude or barometric pressure are shown in figure 4. This correction is in agreement with the findings of Forster and Parker,<sup>5</sup> who calibrated the mini Wright peak flow meter with a mechanical device at sea level and at 4200 m. They found an under-reading of 20%, similar to the correction for this altitude given in figure 4 (21%). The relationship is linear with respect to pressure and therefore curvilinear with respect to altitude. The change in meter measured PEF is about 5%/100 mm Hg reduction in pressure. The correction to be applied to the peak flow meter is 6.6%/100 mm Hg pressure drop. By extrapolation it will be seen that at the summit of Mount Everest (253 mm Hg) the spirometer measured PEF would be increased by 27% over sea level values (if there is no change in dynamic airways resistance) and here any reading from the mini Wright peak flow meter would have to be increased by 33%.

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