Effect of altitude on spirometric parameters and the performance of peak flow meters

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Abstract

Background **– Portable peak flow meters are used in clinical practice for measurement of peak expiratory flow (PEF) at many different altitudes throughout the world. Some PEF meters are affected by gas density. This study was undertaken to establish which type of meter is best for use above sea level and to determine changes in spirometric measurements at altitude.**

Methods **– The variable orifice mini-Wright peak flow meter was compared with the fixed orifice Micro Medical Microplus turbine microspirometer at sea level and at Everest Base Camp (5300 m). Fifty one members of the 1994 British Mount Everest Medical Expedition were studied (age range, 19–55).**

Results **– Mean forced vital capacity (FVC) fell by 5% and PEF rose by 25·5%. However, PEF recorded with the mini-Wright peak flow meter underestimated PEF by 31%, giving readings 6·6% below sea level values. FVC was lowest in the mornings and did not improve significantly with acclimatisation. Lower PEF values were observed on morning readings and were associated with higher acute mountain sickness scores, although the latter may reflect decreased effort in those with acute mountain sickness. There was no change in forced expiratory volume in one second (FEV_1) at altitude when measured with the turbine microspirometer.**

Conclusions **– The cause of the fall in FVC at 5300 m is unknown but may be attributed to changes in lung blood volume, interstitial lung oedema, or early airways closure. Variable orifice peak flow meters grossly underestimate PEF at altitude and fixed orifice devices are therefore preferable where accurate PEF measurements are required above sea level.**

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Keywords: spirometry, altitude, barometric pressure.

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Portable peak flow meters are widely used in clinical practice for measurement of peak expiratory flow (PEF) at many different altitudes throughout the world. At altitude the decrease in air density mechanically causes variable orifice meters, such as the mini-Wright, to underestimate flow.[1–4] An under-reading of 26% at a simulated altitude of 5455 m has been demonstrated in hypobaric chamber experiments.[3] However, fixed orifice spirometers such as the Micro Medical Microplus turbine spirometer have recently been evaluated in a hypobaric chamber and are unaffected by barometric pressure.[4]

In the same way that decreased air density causes variable orifice meters to under-read, by decreasing resistance to respiratory gas flow[5] it causes true PEF to rise at altitude.[3,6] Forced vital capacity (FVC) falls with ascent to altitude[6–9] and a decrease of 3% at 5500 m simulated altitude has been recorded.[6]

We compared the mini-Wright peak flow meter with the a hand held turbine spirometer to assess the performance of the two meters in a field study at altitude. FVC, PEF, and forced expiratory volume in one second (FEV_1) were documented using a turbine spirometer, and PEF using the mini-Wright peak flow meter, in a large study of members of the 1994 British Mount Everest Medical Expedition.

Methods

After obtaining informed consent, spirometric data were collected from 51 members of the 1994 British Mount Everest Medical Expedition (age range 19–55, 36 men) at sea level (barometric pressure 1012·1–1015·5 mB), in the UK (London and Stirling), and within five days of arrival at Everest Base Camp in Nepal (5300 m, barometric pressure 530–547 mB). Ethical approval was obtained.

Spirometric measurements were made according to the recommendations of the British Thoracic Society for respiratory function tests[10] with both a variable orifice mini-Wright peak flow meter (Airmed, Clement Clarke International Ltd, UK) and a fixed orifice turbine spirometer (Micro Medical Ltd, Rochester, Kent, UK). Each forced expiration was performed in a large laboratory tent with an experienced observer. The best of three expirations was recorded for each device. Two hundred and five further spirometric measurements were undertaken with the turbine microspirometer at different times during the first six days at base camp.

Using a standardised acute mountain sickness symptom questionnaire[11] a score was awarded to each subject before the study.

A general linear model was constructed to determine the relationship between the percentage change from sea level in FVC, PEF, or FEV_1 and the acute mountain sickness score and time of day. Oxygen saturation, measured as part of a separate study, was also included in the model. A further linear model was con-

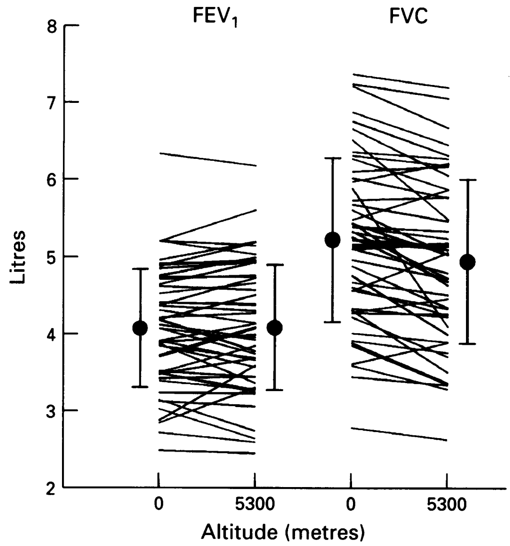

Figure 1 Absolute values, mean and standard deviation (n=51) for forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) at sea level and at Everest Base Camp (5300 m) measured with a turbine spirometer showing no significant change in FEV_1 and a mean fall in FVC of 5·2% at 5300 m ($p<0{\cdot}0001$).

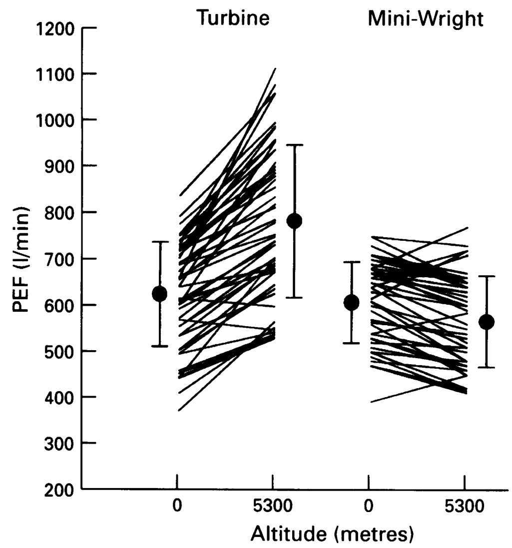

Figure 2 Absolute values, mean and standard deviation for peak flow at sea level and at Everest Base Camp (5300 m) measured with a turbine spirometer (n=51) showing a mean rise of 25·5% ($p<0{\cdot}0001$) and a mini-Wright peak flow meter (n=48) showing a 6·6% fall at 5300 m below sea level values ($p<0{\cdot}0001$).

structed to determine the effect of length of stay at base camp, and therefore acclimatisation, on FVC using 123 spirometric measurements in 14 subjects from one to 45 days after arrival at Everest Base Camp.

FVC, PEF, and FEV_1 measurements at Everest Base Camp were compared with those at sea level and statistical analysis was performed using the Student's *t* test.

Results

At sea level the mean FVC was 5·2 litres (range 2·75–7·36) and the mean PEF using the turbine spirometer was 629 l/min (range 369–838) and 607 l/min (range 390–750) with the mini-Wright peak flow meter. The mean FEV_1 was 4·1 litres (range 2·46–6·32). The differences between the values at sea level and high altitude are summarised in figs 1 and 2.

Using the turbine spirometer (n=51) FVC fell by a mean of 5·2% (95% confidence interval (CI) −3·3 to −7·2; $p<0{\cdot}0001$) at Everest Base Camp compared with sea level, PEF rose by 25·5% (21·5 to 29·5; $p<0{\cdot}0001$) at 5300 m, and there was no significant change in FEV_1 (95% CI −1·9 to 2·1% change). In 48 subjects PEF was also measured with the mini-Wright peak flow meter and fell by 6·6% below sea level values (−4·2 to −9·1, $p<0{\cdot}0001$). The turbine spirometer gave readings which were a mean (SD) of 22 (34) l/min higher than the mini-Wright peak flow meter at sea level, rising to a mean difference of 216 (81) l/min at 5300 m ($p<0{\cdot}0001$). There were no significant sex differences in the spirometric data.

Analysis of variance from the general linear model revealed a significant correlation between PEF, acute mountain sickness score and the time of day, with lower PEF being associated with a higher acute mountain sickness score (coefficient −0·7346, $p<0{\cdot}05$) and morning readings (3·3% lower than afternoon readings, 95% CI 0·9 to 5·7, $p<0{\cdot}01$). FVC was also significantly related to the time of day, with a lower FVC being recorded in the morning ($p<0{\cdot}01$), but was not related to acute mountain sickness score.

The second linear model, constructed to determine the effect of length of stay at base camp (and therefore acclimatisation) on FVC, showed no statistically significant improvement in FVC with time at base camp in 14 subjects from whom data were available, although there was a trend towards sea level values.

Discussion

Our data show a 5% fall in FVC with ascent to 5300 m as has been observed by others.[6–9 12] Some authors have found that the FVC returns to normal after a period at altitude of seven days,[7 8] but this was not confirmed by Ulvedal *et al*[6] after a similar seven days of acclimatisation. We noted a trend towards sea level with time at base camp in a limited number of subjects, but this was not statistically significant.

Several different explanations have been proposed for this fall in FVC. An increase in pulmonary blood volume would reduce the FVC but, in a short exposure to hypoxia, Doyle *et al*[13] found no change in pulmonary blood volume. Our finding of lower values for FVC in the morning probably reflects accumulation of fluid in the supine position overnight, but the measurements were of a similar order to the fluctuations observed by others in healthy subjects at sea level.[14] Both oedema and an increased lung blood volume might return to normal with a corresponding return to sea level values of FVC after acclimatisation, as observed by others,[7 8] although we did not find this. Welsh *et al*[15] on Operation Everest II performed spirometric studies during a 40 day hypobaric chamber experiment and found a progressive fall in FVC which only resolved slowly (over 48 hours) after descent which they also attributed to increased pulmonary blood volume and oedema. Rahn and Hammond[7] suggested that expansion in intra-abdominal gases might compress the diaphragm and cause a fall in FVC but this was later ruled out by Ulvedal *et al.*[6] Oxygen absorption from the lung accounts for about 1·6% of the 7·6% fall in FVC at 10 000 m.[6] Interstitial or intra-alveolar oedema may be the cause of the fall in FVC at altitude.

In long distance runners a fall in FVC is accompanied by an equivalent rise in residual volume thought to be brought about by early closure of the small airways, possibly due to an increase in extravascular lung water.[16 17] Early closure of the airways might account for the fall in FVC at altitude. If this is so there should be an equivalent rise in residual volume and no change in total lung capacity. Tenney *et al*[8] found that, on the first day on Mount Evans in Colorado, total lung volume was increased in four subjects due to a rise in residual volume greater than the fall in FVC. However, on the third day FVC fell further and total lung capacity dropped below sea level values. Thereafter there was no clear pattern in lung volume changes.

Fixed orifice spirometers such as the Micro Medical Microplus turbine spirometer have recently been evaluated in a hypobaric chamber and were found to be unaffected by barometric pressure.[4] Our data, using this device, confirm the finding that PEF rises by 25·5% at 5300 m, with barometric pressure about half that at sea level. It has long been recognised that decreasing gas density decreases resistance to respiratory gas flow[5] and this large field study confirms the finding in hypobaric chamber studies that true PEF rises at altitude.[3 4 6]

Variable orifice devices such as the mini-Wright peak flow meter[18] provide repeatable but non-linear responses at sea level, over-reading in the middle of the range.[19] At altitude, however, the decrease in air density mechanically causes the mini-Wright to underestimate flow.[1-3] Our data confirm a 6·6% fall in PEF measured with the mini-Wright meter representing an underestimate of 31%. This is similar to the under-reading of 26% at a simulated altitude of 5455 m demonstrated in hypobaric chamber experiments.[3] Thomas *et al*[3] showed that the underestimation of the mini-Wright meter could be corrected by adding 6·6% per 100 mmHg. This is supported by our data where a correction factor of 6·5% applies.

The effect of humidity and temperature on the measurements of PEF with either device is uncertain. However, Pedersen *et al*,[4] using the Micro Medical spirometer, could not detect any change in PEF from dry to fully saturated air at 37°C (but they predicted that there would be a 1·2% fall). The Micro Medical spirometer has also been tested after three weeks at −4°C when an under-reading of only 1% was found compared with measurements at the same flow at 25°C (M R Miller, personal communication). Indeed, these observations are not surprising as the temperature at the turbine is relatively unaffected by ambient temperature. At 5°C ambient temperature the expired air temperature measured with a fast thermistor was 30°C at the turbine, and at 20°C ambient temperature it was 31°C (C Lawson, Technical Department, Micro Medical, personal communication).

Two studies have shown a correlation between acute mountain sickness and decreased PEF. Singh *et al*[20] looked at PEF in subjects suffering from acute mountain sickness and found a significant reduction in PEF compared with sea level values which was greatest in those individuals with the most severe symptoms. Stockley *et al*[12] also measured PEF before, during, and after a 21 day Himalayan trek and demonstrated a significant drop in PEF in subjects who were severely affected with acute mountain sickness (above 3100 m) but not in individuals with mild symptoms. However, these studies did not take into account the effect of the change in air density, and the effect of density on measurement of resistance/airflow at altitude. Our data support their finding of a significant association between lower PEF and higher acute mountain sickness scores. However, we suspect that expiratory effort may be decreased in those symptomatic with acute mountain sickness.

FEV_1 was unchanged at 5300 m compared with sea level values in our study. This reflects the opposing forces of the higher early flow at high altitude in the face of a reduced vital capacity and is supported by previous observations.[15] The FEV_1/FVC ratio is therefore increased at altitude as the FVC falls.

Portable peak flow meters are used in clinical practice for measurement of PEF at many different altitudes. Although there is considerable experience of variable orifice devices at sea level, their inaccuracies in mid-flow ranges have only recently been appreciated. These devices underestimate PEF at altitude and we would therefore suggest that fixed orifice devices are preferable. If variable orifice devices are used at altitude, results should be corrected for air density (barometric pressure).

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