Effect of spirometer temperature on FEV\textsubscript{1} in a longitudinal epidemiological study

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Abstract

Objectives—To assess the magnitude of error in pulmonary function measurements introduced by variation in spirometer temperature under field conditions. In a large scale epidemiological study of school children, the influence was investigated of spirometer temperature on forced expiratory volume in 1 second (FEV\textsubscript{1}) measured with dry rolling seal volumetric spirometers and conventional body temperature, pressure, and saturation (BTPS) corrections.

Methods—Linear regression analyses were performed on data from 995 test-retest pairs on 851 different children, with 1–110 days between test and retest, and spirometer temperature differences between −13°C and +9°C.

Results—After adjusting for effects of growth (test-retest intervals) and circadian variation (changes in times of testing), differences in standard BTPS corrected FEV\textsubscript{1} showed significant (p<0.05) dependence on differences in spirometer temperature between tests (−0.24%/°C).

Conclusions—When spirometer temperatures vary widely, standard BTPS correction does not fully adjust for gas contraction. To improve accuracy of volume measurements in epidemiological studies, additional correction for variation in spirometer temperature should be considered.

Keywords: spirometry; epidemiology

Measurements of forced expired volume in 1 second (FEV\textsubscript{1}) or peak flow with volumetric spirometers, and conventional corrections to 37°C body temperature, pressure, and saturation (BTPS), assume instantaneous transition of exhaled air from body temperature to spirometer temperature. Within the normal room (or spirometer) temperature range, the actual transition is not instantaneous; consequently, the measured air may contract less than is assumed, and the BTPS corrected volume or flow may be too large.\textsuperscript{1–4} If the magnitude of the overestimate is substantial, use of the conventional BTPS correction may introduce inaccuracies. Laboratory and field studies indicate that the magnitude of the overestimate in volume or flow may be large enough to warrant additional correction.\textsuperscript{1–4} Hankinson and Viola\textsuperscript{1} measured the effect of varying spirometer temperature in a laboratory, with a typical dry rolling seal spirometer (Ohio Medical Products Model 840) and a physical system capable of delivering reproducible simulated forced expirations of water vapour saturated air at 37°C. They found that the conventional BTPS correction had an undetectable effect on measured FEV\textsubscript{1}, at 32°C spirometer temperature, but that error in calculated FEV\textsubscript{1}, increased in a nearly linear manner as temperature decreased, averaging 3.1% at 20°C and 7.7% at 3°C. These laboratory studies show that additional corrections beyond application of the standard BTPS factors may be needed, especially when the range in spirometer temperatures is large.

In epidemiological studies that use FEV\textsubscript{1} measurements conducted in field settings, spirometer temperature may vary over a range nearly as large as in these laboratory studies. Variation introduced by ignoring the effect of spirometer temperature on BTPS corrected FEV\textsubscript{1} has not been extensively studied in field settings. Judging from the laboratory results, such variation may cause non-differential measurement error and reduced statistical power if spirometer temperatures vary at random, or differential bias if temperatures differ systematically at different times or locations. To determine whether the relation between standard BTPS corrected FEV\textsubscript{1} and spirometer temperature as reported by Hankinson and Viola occurs in data collected under field conditions with wide ranging temperatures, we examined repeated pulmonary function measurements from a large scale field survey of school children. We assessed the relation between changes in spirometer temperature and measured pulmonary function change, after accounting for other potential sources of variability in spirometer measurement\textsuperscript{1–6} and time dependent effects.
Regression results: change in FVC or FEV₁, v temperature and time factors

<table>
<thead>
<tr>
<th>Data analysed</th>
<th>Test</th>
<th>n</th>
<th>Intercept*</th>
<th>Temperature (°C)</th>
<th>Time of day (h)</th>
<th>Age (y)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable subjects</td>
<td>FVC</td>
<td>892</td>
<td>-0.63</td>
<td>-0.20 (−0.09 to −0.31)</td>
<td>0.06 (~0.14 to 0.26)</td>
<td>7.8 (3.6 to 11.4)</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>879</td>
<td>-1.10</td>
<td>-0.24 (−0.12 to −0.36)</td>
<td>0.22 (0.00 to 0.44)</td>
<td>9.6 (4.9 to 14.3)</td>
<td>0.031</td>
</tr>
<tr>
<td>Good subjects</td>
<td>FVC</td>
<td>649</td>
<td>-0.77</td>
<td>-0.21 (−0.08 to −0.34)</td>
<td>0.06 (~0.16 to 0.28)</td>
<td>8.6 (3.6 to 13.6)</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>FEV₁</td>
<td>646</td>
<td>-1.22</td>
<td>-0.24 (−0.10 to −0.38)</td>
<td>0.27 (0.02 to 0.52)</td>
<td>10.6 (5.2 to 16.0)</td>
<td>0.034</td>
</tr>
<tr>
<td>All lab tests (1)</td>
<td>FEV₁</td>
<td>†</td>
<td>8.09</td>
<td>-0.25 (−0.24 to −0.26)</td>
<td>—</td>
<td>—</td>
<td>0.99</td>
</tr>
<tr>
<td>Lab tests 13–29°C</td>
<td>FEV₁</td>
<td>‡</td>
<td>8.11</td>
<td>-0.25 (−0.22 to −0.28)</td>
<td>—</td>
<td>—</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* In subject tests, regression intercept represents theoretically expected FVC or FEV₁ change from test to retest with no change in temperature or time. In lab tests, intercept represents expected FEV₁ difference between measurements at 0°C and 32°C.
† Twelve waveforms tested at 11 temperatures from 3–32°C.
‡ As above, seven temperatures from 13–29°C.

Methods

More than 3000 children, attending elementary, intermediate, and high schools in 12 different communities, were tested at their schools during winter or spring of 1993, 1994, and 1995. Forced expiratory variables including forced vital capacity (FVC) and FEV₁, were measured with Spiroflow Model 132 spirometers (P K Morgan, Gillingham, UK), which are physically similar to the spirometer tested by Hankinson and Viola. All lab tests were performed on the data of Hankinson and Viola for FEV₁ produced by their laboratory simulator loaded with saturated air (table 1 in reference 1), both for their entire temperature range (3°C–32°C), and for the range most relevant to our test-retest data (13°C–29°C). These additional regressions related the weighted mean error at each spirometer temperature (the mean percentage difference between actual and BTPS corrected FEV₁, weighted by the inverse of the SD) to spirometer temperature itself, rather than temperature change.

If our spirometric measurements calculated with conventional BTPS correction were subject to temperature related errors comparable with those found by Hankinson and Viola, then all the analyses would be expected to yield similar regression slopes for % change in FEV₁. For FVC, Hankinson and Viola found little temperature related error, as expected because their technique allowed time for thermal equilibration. In most of our subjects, however, FVC exhalation was essentially complete in 1–2 seconds, so that incomplete thermal equilibration and temperature related error might be expected for FVC as well as FEV₁.

Results

The table summarises the regression results. Either the acceptable or the good test-retest data showed significant (p<0.05) negative relations between % change in FEV₁, and change in spirometer temperature, with estimated slopes near −0.24%/°C, nearly the same as the slope of −0.25%/°C estimated from the published laboratory data. The age (growth) effect was also significant, with estimated slopes near 10%/year. The time of day (circadian) effect was at least marginally significant, with estimated increases in FEV₁, >0.2%/hour, after allowing for the temperature effect. For FVC, the effect of spirometer temperature change was slightly smaller than for FEV₁, but was still significant. The age effect also was slightly smaller for FVC than for FEV₁. The FVC showed no significant circadian effect.
Discussion
We found that the assumption of instantaneous cooling of exhaled air, implicit in conventional BTPS correction methods, is not entirely valid for spirometry conducted under field conditions where large variations in spirometer temperature are encountered. Conventionally BTPS corrected FEV1, and FVC data from our large scale field survey of children depended greatly on spirometer temperature. The size of the temperature effect was essentially the same as found by Hankinson and Viola in laboratory simulations with a similar spirometer, but different from that reported by Perks et al. in human testing, or by Pincock and Miller in laboratory simulations, with differently designed volumetric spirometers. Thus, the close agreement between our results and those of Hankinson and Viola may depend on similar spirometer designs. Error correction procedures should be made specifically for the equipment used and the temperature range experienced in a given study.

The implications of spirometer temperature variation for studies of changes in lung function during a working shift have been discussed previously. The implications for longer term longitudinal surveys or cross sectional surveys also need to be considered. From our results, it seems that a mean temperature difference of 4°C–5°C from one test circumstance to another would artifactually shift the estimated mean FEV1 by 1%. An effect of this size, if not taken into account, may introduce meaningful change in estimates of other effects.

Circadian variation also seemed to influence our measurements of FEV1, but not FVC, with a slightly smaller effect size and level of significance than the effect of spirometer temperature. It represents another subtle influence which needs to be accounted for to estimate longer term effects accurately.

As expected, our simple analytical model explains only a small proportion of the variance in test-retest lung function differences. Acute changes in underlying health, recent environmental exposures, and varying genetic or environmental influences on lung growth probably explain more of the variance, and will be considered in future investigations. In general, these substantive influences would not be expected to correlate with spirometer temperature, and so are not likely to bias our estimates of its effect.

The statements and conclusions in this report are those of the contracted and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with our results is not to be construed as either an actual or implied endorsement of such products. This study was supported by the California Air Resources Board (Contract No 5P30ES07048–02), the Environmental Protection Agency (Contract No CR824034–01–3), and the Hastings Foundation. We acknowledge the cooperation of the study communities, the school principals, the many teachers, the students and their parents.


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